Final report

OWMC
Ontario
Waste Management
Corporation

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Battelle

HAZARD ANALYSIS OF OWMC TREATMENT FACILITY
Summary of Facility Risk for Typical Waste

FINAL REPORT

by

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21 December 1988

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Attention: Dr. Chih C. Chao, P. Eng.
Process Design Coordinator

Dear Sirs:

RE: Hazard Analysis of OWMC Treatment Facility

We are pleased to submit the report entitled "Hazard Analysis of OWMC Treatment Facility: Summary of Facility Risk for Typical Waste". This document is submitted in support of Monenco's Design and Operations report (1988) with respect to the facility risk to the public due to potential process upsets and accidents.

This report presents the estimated accident risk to the public based on the current preliminary design and plans for operating the proposed facility. This estimate is based on typical waste streams as defined by a generator survey and current knowledge of parameters such as chemical toxicity and population distributions. We understand that OWMC will continue to investigate measures to reduce the residual accident risks. Necessary measures will be implemented during detailed engineering.

Sincerely,

Fred L Leverenz Jr

Fred L. Leverenz, Jr.
Program Manager
OWMC Hazard Analysis

FLL:djd

Enclosure

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EXECUTIVE SUMMARY

The Ontario Waste Management Corporation (OWMC) is proposing to construct and operate an integrated facility for treating and disposing of hazardous wastes and liquid industrial wastes. The proposed location of the OWMC Treatment Facility is in West Lincoln, Ontario. A preliminary design, which has a projected initial capacity of 150,000 tonnes per annum (t/a) with the capability to expand to 300,000 (t/a), has been developed as a basis for an environmental assessment (OWMC, 1988) which includes the first results from an ongoing hazard analysis.

A hazard analysis is an investigation of acute risks from abnormal operation or behavior of a facility. The acute risks, with near term effects ranging from reversible health effects to fatalities, result from relatively infrequent accidents or process upsets. An accidental mixing of incompatible chemicals which generates toxic vapors which are released and dispersed to a populated area is an example of an accident with an acute risk of near term or immediate health effects.

This report describes the purpose, the methodology and the results of the first risk estimates from the hazard analysis, limited to offsite risk of the preliminary facility design and the treatment of typical wastes.

Purpose of the Hazard Analysis

Accidents and operational upsets can occur at any industrial facility, including the proposed OWMC Treatment Facility. Most of these accidents/upsets do no harm beyond the time and expense of repairs and loss of operating time. Some, however, may be a threat to the health and safety of the public and facility employees. It is important to identify the accidents/upsets that might occur at a facility and to study them to determine which need attention to protect the health of the public/employees.

In the process of identifying and examining the hazards and potential accidents, changes in the design or operating procedures which will eliminate the hazard or at least reduce the risk of the accident are developed. The design or procedure that is modified can then be reexamined to see if the risk has been reduced sufficiently. This iterative process is continued until the residual (remaining) risk of the individual accidents and upsets and the residual risk of the facility as a whole, the "Summary of Facility Risk", is deemed acceptable.

The identification and evaluation of risks, the reduction of risks where necessary, the reevaluation of the design/procedure to estimate the residual risk and the summary of facility risk will provide essential input to finalizing the design and operation details of the OWMC Treatment Facility. Furthermore, during construction and subsequent operation of the facility the information developed in the hazard analysis will be used to develop inspection and audit protocols and to ensure that any future repairs or modifications do not introduce new hazards.

Accidents and Their Consequences

An accident is an event, or a sequence of events, which is initiated by an unintended (accidental) event, such as an equipment failure or operational error, and may result in an undesirable consequence. The intermediate events may be intentional, such as actions which protect against continuation of the accident sequence, or unintentional, such as additional failures or errors. For example, consider a fire in the home. A possible sequence of events could include a fireplace fire left unattended (the hazard), a spark from the fire igniting the carpet (the initiating event), the smoke detector alerting the occupants (an intended intermediate event), the extinguishing of the fire by the occupants or fire department (another intended intermediate event), and the damage done by the fire (consequence). If the fire department had gone to the wrong address that would have been another (unintended intermediate) event. Clearly, each of these events has a likelihood of success and degree of effectiveness which affects the likelihood and consequence of the accident.

In an industrial facility there are usually many different types of potential accidents -- each accident type representing the accidents which have the same type of initiating event (e.g., a spill of material), the same types of intermediate events (e.g., fire, dispersion of vapor), and the same type or types of potential consequences (e.g., blast effects, thermal radiation, toxic exposures). Eight different types of potential accidents were identified for the OWMC Facility.

Within each accident type, the potential accidents can have different likelihoods and consequences depending upon the likelihood and magnitude of the initial event and intermediate events; where in the facility the accident occurs; and the amount and physical, chemical, and toxicological properties of the materials involved. The OWMC Hazard Analysis identified over 10,000 ways, i.e., 10,000 different accident scenarios (event sequences), in which the different types of accidents and process upsets might occur.

Definitions of the Elements of Risk

Risk represents both the likelihood and the consequences of an activity or event. By studying the activity or event, both the likelihood of its happening and the consequences of its happening can be determined or at least estimated. In the example discussed earlier, a fire in the home involves the likelihood (chance) that it will occur and the consequence(s) (loss of property and perhaps life) if it does occur. Insurance statistics can provide an estimate of the likelihood and an inventory of property and persons could provide an upper bound to the consequences. It would then be possible to obtain an upper bound for the risk in terms of both likelihood and consequence for comparison to other risks. In hazard analysis, risk is a function of likelihood and consequence.

Likelihood can be described as how many times an event, or sequence of events, is expected to occur over a period of time. The value of the likelihood of an accident depends upon the particular event or sequence of events associated with it and the likelihood of each of those events.

Consequence(s) can be described as the result or results of a particular event or sequence of events. As with the likelihood, each different sequence of events may have a different result in quantity and/or in kind and hence a particular consequence depends upon the particular sequence of events that is associated with it.

Measures of Risk

Hazard analysis involves exhaustive identification of hazards and accident event sequences and the estimation of both their likelihood and consequences; hence, the risk results can be numerical. The risks are often most easily understood if they can be compared to other risks with which individuals are familiar such as driving a car, accidents in the home or workplace, etc. Two measures of risk are usually estimated and compared with the corresponding measures for the other risks. These two measures can be termed "individual" and "societal" risk. The individual risk measure specifies the maximum level of risk to which any individual may be exposed by the activity being analyzed. The societal risk measure expresses the risk to society as a whole, i.e., how many people can be affected and in what way from that activity.

The OWMC Treatment Facility Hazard Analysis estimates the risk at three different consequence levels (reversible health effects, irreversible health effects, and fatalities). Available data and criteria on acute risk typically relate only to the frequency of fatalities for normal, healthy individuals. Therefore, whereas it is possible to compare the frequency of fatalities from the OWMC Facility directly to the frequency of fatalities from other facilities and activities, the lack of data on the frequency of reversible and irreversible health effects from other activities prevents comparisons of the frequency of these lesser effects. However, comparisons of the probable frequency of these lesser effects from the OWMC Facility to the frequency of fatalities from other causes can be helpful in judging the safety of the OWMC Facility provided the difference in the consequence level is recognized.

The Methodology Used in the Hazard Analysis

The hazard analysis was a joint effort of several OWMC consultants lea by Battelle Columbus Division (BCD). Representatives of OWMC, Monenco (OWMC Treatment Facility designer), ORTECH International (atmospheric dispersion consultant, formerly Ontario Research Foundation), and ENVIRON (health risk consultant) participated.

The major steps in the hazard analysis were

- Identification of potential accidents/upsets
- Estimation of potential consequences of the accidents/upsets
- Implementation of appropriate risk reduction measures for the accidents/upsets which have consequences of concern
- Reestimation of potential consequences of the accidents/upsets where risk reduction measures have been implemented
- Estimation of the likelihood of the accidents/upsets which, after risk reduction measures have been taken, continue to have consequences of concern
- Estimation of residual risk of the individual accidents/upsets with consequences of concern by combining their likelihood and consequences
- Estimation of residual facility risk (summary of facility risk) by combining the risk estimates of individual accidents/upsets

It is important to recognize that these steps are carried out in an iterative fashion. This was done, and will continue to be done, to allow the hazard analysis process to benefit various stages of facility design so as to continually reduce the risk to a lower level. Figure A shows that this iterative process first concentrates on reducing consequences, then, when necessary, addresses likelihood reduction.

Identification of Potential Accidents and Process Upsets

The OWMC Treatment Facility Hazard Analysis used the Hazards and Operability Study (HAZOPS) method for identification of potential accidents and process upsets and their consequences. This is an internationally recognized method for examining a proposed activity or facility, identifying the hazards and potential accidents, and identifying potential risk reduction measures. It is a highly structured and extremely rigorous process. The HAZOPS method involves a point-by-point examination of the facility by an expert team. The HAZOPS team is comprised of several individuals who, collectively, are knowledgeable of all aspects of the facility being examined and other individuals who are experts in the HAZOPS

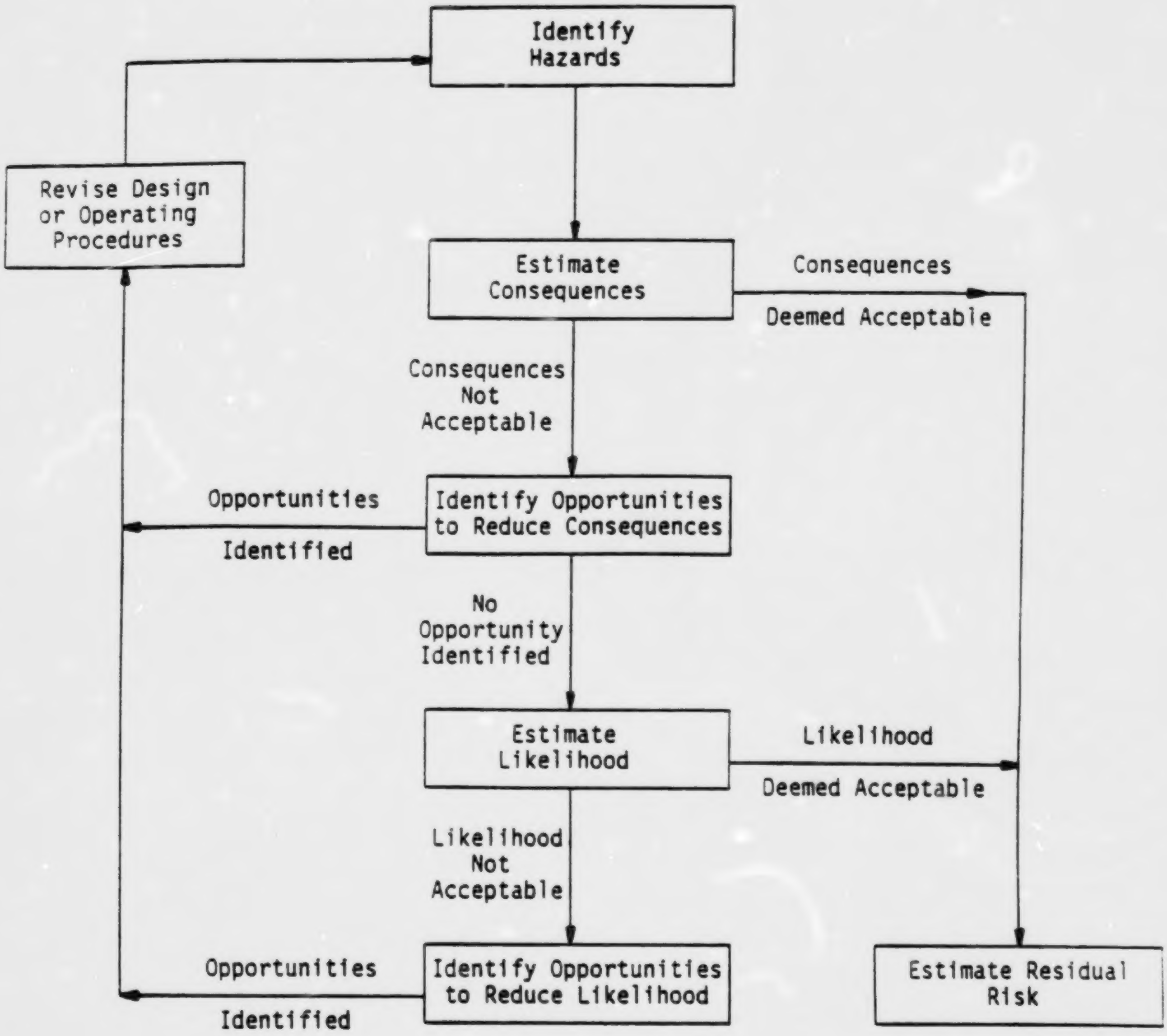
Identify Hazards
Revise Design or Operating Procedures
Estimate Consequences
Consequences Deemed Acceptable
Consequences Not Acceptable
Opportunities Identified
Identify Opportunities to Reduce Consequences
No Opportunity Identified
Estimate Likelihood
Likelihood Deemed Acceptable
Likelihood Not Acceptable
Opportunities Identified
Identify Opportunities to Reduce Likelihood
Estimate Residual Risk

FIGURE A. ITERATIVE NATURE OF HAZARD ANALYSIS method and have experience in Hazard Analysis of other facilities. Extensive records are kept of the discussions and results of the HAZOPS sessions.

Twenty-one HAZOPS sessions, each several days long, were held during the OWMC Treatment Facility Hazard Analysis and over 10,000 potential accident scenarios were identified, either in the sessions or in later study of the HAZOPS records and facility drawings.

Analysis of Facility Risk

The identified accident scenarios were then analyzed to estimate the potential consequences from causes such as equipment failures, operating errors, and external natural events. Potential exposure of the public in the neighborhood of the proposed OWMC Facility to fires, explosions, and/or releases of toxic materials was evaluated to estimate the extent of: reversible health effects (effects that disappear after exposure such as eye irritation and coughing); irreversible health effects (effects that persist after exposure such as diminished lung capacity); and fatalities that might be caused by individual accident scenarios that had been identified. When reversible, irreversible, or fatal consequences were estimated to occur outside of the 400-m buffer zone, after consideration of design changes, the likelihood that the accident scenario or external event could occur was estimated. The likelihood estimates were based on data or estimates of the frequency of contributing component failure, operator error, or natural events. Finally, the potential consequences and the probability of occurrence of accident scenarios were combined to estimate the residual risk of the proposed OWMC facility. This residual risk to the public (outside of the 400-m buffer zone) is described qualitatively in the next section.

Results of the Hazard Analysis

As indicated earlier, two measures of risk were estimated for comparison with the corresponding measures for risks of other activities. The individual risk measure specifies the maximum level of risk to which any individual may be exposed; the societal risk measure expresses the risk to society as a whole.

Individual Risk of the OWMC Treatment Facility

Individual risk to the public is estimated for the "maximum exposed individual" in the OWMC Hazard Analysis. This hypothetical person is presumed to be an average, healthy adult living on the edge of the facility buffer zone (400 m from the perimeter of the core zone which is within the Central Operations Area of the facility) 24 hours per day, 365 days per year, for the lifetime of the facility, and located at the spot along the buffer zone where the maximum likelihood of exposure for each potential accident scenario occurs. This person is also assumed to be average in terms of size and age and to be in good health. This method for estimating individual risk for the OWMC Treatment Facility is clearly conservative; the actual risk to any healthy adult living outside of the 400-m buffer zone would be less than that predicted for the hypothetical "most exposed individual". (There may be more sensitive individuals who are more likely to experience an adverse health effect compared to the average, healthy adult.)

The OWMC Hazard Analysis estimated the acute individual risk of fatality for the "maximum exposed individual" to be similar to the risk of the average person being killed by accidental falls. It may also be stated that this individual risk level is similar to the estimated risk from a coal-fired power plant and less than the estimated risk from refineries at Canvey Island*. This risk level is also below the risk level for individuals summed over all accidents they are normally exposed to (car, farm, airplane, etc.). Also, the OWMC Hazard Analysis identified no accident scenarios which have fatalities outside of the Property Value Protection Zone.

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* Canvey Island is a dense complex of chemical and petrochemical manufacturing and storage facilities adjacent to a populated area in Great Britain. It was the site of the first detailed, comprehensive risk assessment of a nonnuclear industrial complex.

Societal Risk of the OWMC Treatment Facility

While the OWMC Hazard Analysis estimates the societal risk for all three levels of health effects, there are even fewer comparisons available than for individual risk. One which can be used for comparison is the societal risk goal which The Netherlands has put into law. This law requires all facilities to estimate their risk, and to make facility changes if the risk is above a specific limit. Further, it can be said that this goal is the most stringent currently being imposed by any legislative body in the world. The estimated societal risk for the OWMC Treatment Facility is such that if the facility, with its 400-m buffer zone and surrounding population density, were located in The Netherlands it would meet their societal criteria such that no facility modifications would be required.

Another way of looking at the societal risk is to compare the expected fatalities for a group of people over time in the vicinity of the facility. Specifically, for the population currently living within the Property Value Protection Zone over the next 70 years (OWMC Treatment Facility lifetime), the expected fatalities from the OWMC Treatment Facility is about one-half of those expected from lightning, about one-tenth of those expected from electrocution, and less than one-thousandth of those expected from motor vehicles.

Benefit of Hazard Analysis to Design Process

A primary objective of this hazard analysis was to identify modifications to the proposed design and operation of the OWMC Facility that can be made to reduce risks to the surrounding community. Such modifications have been made during the course of the hazard analysis. For example, the hazard analysis identified various ways that simple human errors could result in the wrong chemical being added to wastes during their treatment. Some of these errors could result in generation of toxic gas at a high rate. A much more rigorous procedure was developed to eliminate the simple human errors, including the provision of a bar code system to track materials and allow the computer to check-on or block operator actions. This is similar to the systems implemented in grocery stores to read prices from merchandise at the checkout stand, with the added feature that the operator and computer must agree. That is, for the grocery store to be as reliable as the OWMC system, the clerk would have to first key in the price and then read in the bar code. Computer agreement of the keyed price and the bar code price would be required before the price would be entered for tabulation. To further reduce the consequence of such accidents, design features, such as adding restrictions to control valves to limit the chemical transfer rate, thus reducing the toxic release rate, could also be changed.

Conclusions

These acute risk estimations, based on the latest design and operating procedures, are providing feedback to OWMC and designers on the best options for continued risk reduction and will also provide up-to-date residual risk estimates, assuring design and operation of the facility will not add significant risk to workers or the public.

The hazard analysis will continue to be used as a basis for the acute risk reduction as subsequent design and operations options are considered. In this way the hazard analysis will be as much a part of the facility design process and its documentation as are the drawings and equipment specifications and will be kept up to date as the design is finalized.

The current estimated residual risk, taking no credit for subsequent design improvements, as measured by individual and societal risk measures, indicates that this facility can be operated without adding significant risk to the surrounding population. Furthermore, the estimated residual risk does not contradict the selection of the 400-m buffer zone, even though this selection was based on a preliminary accident scenario evaluation, and, further, demonstrates that the buffer zone serves to reduce public risk.

HAZARD ANALYSIS OF OWMC TREATMENT FACILITY

1.0 INTRODUCTION

A hazard analysis of the proposed Ontario Waste Management Corporation (OWMC) Treatment Facility has been performed by Battelle Columbus Division with support from Monenco Limited (Monenco), ORTECH International (ORTECH) and ENVIRON Corporation (ENVIRON). The OWMC Facility is described briefly in Section 1.2 of this report. Additional detail can be obtained from "OWMC Treatment Facility - Design and Operations" prepared by Monenco, engineering consultant to OWMC (OWMC, 1988b).

A preliminary hazard analysis was made in May and June of 1986 (Battelle, 1986). A detailed analysis was initiated in April of 1987. This report describes the approach, methods, and results of the detailed analysis.

1.1 Overview of Hazard Analysis

Hazard analysis, as defined and described here, is concerned with potential accidents or upsets, during the operation of a facility or other engineered system, that could endanger the health and safety of the employees or neighboring public. In some instances it is also concerned with property and other economic losses, but this is usually a secondary consideration. It is not concerned with hazards such as fugitive emissions that may be a part of the normal operation of the facility when everything is functioning as intended. Such hazards represent chronic risks and have been analyzed and reported in "OWMC Site Assessment, Phase 4B: Risk Assessment" (ENVIRON, 1988). A hazard analysis is concerned with episodic events caused by equipment failures, human errors, and natural events such as tornadoes and earthquakes that may result in acute effects on human health and safety.

1.1.1 Purpose of the Hazard Analysis

The purpose of a hazard analysis is to identify and evaluate the risks to health and safety from process-related accidental events. Estimates of the consequences and the likelihood of occurrence of such accidents/upsets are combined to estimate the risk to employees and the public.

A Hazard Analysis consists of a series of steps which:

- Identify potential accidents/upsets
- Estimate the potential consequences of the accidents/upsets
- Estimate the likelihood of the accidents/upsets having significant consequences
- Estimate the risk of individual potential accidents/upsets by combining the severity of consequences and the likelihood of occurrence
- Estimate the facility risk by summing the risk estimates of the individual potential accidents/upsets.

The methods of hazard analysis are designed to permit systematic examination of a facility to identify all important hazards and the potential accidents associated with them and to provide estimates of the consequences and likelihood of the accidents. These estimates can then be used to provide estimates of the risk that can be attributed to each of the accidents as well as to provide estimates of the risk of the entire facility or system.

The hazard analysis can also contribute to the identification and evaluation of measures for additional protection against risk, if the risk estimates indicate a need. In this way, hazard analysis may contribute to system design and policy decisions. Though there are many other considerations (e.g., financial, political, sociological, etc.) that are not a part of hazard analysis that are equally important to those decisions, hazard analysis can help designers and policymakers understand the potential consequences and risks of alternative courses of action that are available.

1.1.2 Definitions: Hazards, Consequences, Accidents, Likelihood, and Risk

Some definitions will help the understanding of hazard analysis. It is convenient to think of a hazard as a situation, set of circumstances, or inherent physical or chemical property that could result in an undesirable consequence if an accident or process upset involving the hazard should occur. In the chemical process industry a hazard is usually associated with a loss of containment of a hazardous material or an uncontrolled release of a large amount of energy under circumstances where the health and safety of individuals are threatened. An accident then becomes the event or the sequence of events which causes the release of hazardous material or energy and determines when and where the undesirable consequences may occur.

The risk associated with an accident is defined by the estimated consequences of the accident and the estimated likelihood that the accident, and its consequences, will occur. Often the product of likelihood and consequences is equated to risk, though it is not always such a simple relationship; sometimes the estimated consequences are such that little consideration is given to the likelihood and decisions and actions are based almost solely on the magnitude of the consequences. With these definitions of hazard, accident, and risk in mind, the elements/steps of hazard analysis, and some methods for accomplishing the steps, can be described.

1.1.3. Identification of Hazards and Potential Accidents

The first step of a hazard analysis is to identify the hazards inherent in the facility or system under analysis. For example, an identification of the amount and location of toxic or high-energy materials is usually necessary. The next step is to determine the consequences of concern. These may range from toxic exposures of large populations to thermal or chemical burns from leaks, fires, and explosions. Hazards and consequences are closely related, but there are advantages to maintaining a distinction between the two terms. For example, measures for reducing the risk by hazard reduction (e.g., reducing the inventory of the hazardous material) may differ from those used for consequence reduction (e.g., incorporation of mitigation measures such as fire-extinguishing equipment).

The next step of a hazard analysis is to establish qualitative decision criteria which can be used to screen the accident scenarios as they are identified. The qualitative criteria will set conservative limits to the levels of consequences, likelihoods, and/or risks that will be considered unimportant at this stage of the analysis. Accident scenarios judged to have consequences, likelihoods, and/or risk within the criteria limits will need no further analysis; scenarios which have consequences, likelihoods, and/or risks outside the criteria will initiate changes in design or operating procedures to meet the criteria or will be referred to quantitative analysis for a more precise determination of the risk and/or risk parameters. This may involve establishing corresponding quantitative risk criteria.

With the inventory of hazardous materials, the consequences of concern, and the decision criteria determined, attention can be given to identifying the potential accidents which could involve one of the hazards and result in an undesirable consequence.

An accident is usually a combination or sequence of events rather than just a single event. This is especially true when the accident is in an industrial facility with both equipment and human operations involved. It is necessary to recognize and understand all of the important events in an accident, and their interrelationships, in order to be able to predict the likelihood and the consequences of the accident. Thus, in hazard analysis it is common to think of an accident as a sequence of events and to refer to it as an accident sequence (of events) or an accident scenario.

Each accident scenario is a sequence of events beginning with a basic cause and ending with a consequence. The contributing causes may be equipment failures, human errors, or external natural events. The immediate result of the cause, or causes, is an initial accidental event such as a spill of a hazardous material. This is followed by subsequent events which involve the behavior of the system in its response to the initial accidental event. These subsequent events involve physical processes such as evaporation and dispersion of a spilled material and the behavior of systems, automatic equipment, and human actions that have been provided to prevent or minimize the consequences of the accident.

There are a number of formal methods for identification of potential accident scenarios (AIChE, 1985). While all of these methods are systematic and comprehensive in order to be effective, there are two basically different approaches. If the plant or system has been in operation for a period of time, or is a near replica of existing facilities for which there is a considerable body of documented experience, including accident experience, this experience can be used for facility design and as a basis for generating checklists for safety reviews prior to operation. Any differences in design, operation, maintenance routines, etc. should be examined in greater detail, even to the point of performing engineering analysis of the behavior of new elements under upset conditions.

If there are no precedents for design and operation from a safety point-of-view, a different type of hazard analysis is necessary. This type of analysis must be just as systematic and comprehensive, but it must also be creative in postulating failures and accident scenarios which are not available from experience. "What If" Analysis and Failure Modes and Effects Analysis (FMEA) have been widely used for a variety of systems but the Hazards and Operability Study (HAZOPS) method has been found to be especially useful for chemical process facilities. The HAZOPS method focuses on the process parameters at particular lines and vessels in the process. It systematically hypothesizes individual deviations in the process parameters and attempts to identify and evaluate their causes, consequences, and the protection provided. If the consequences are significant, it attempts to estimate the likelihood of that deviation occurring and the effectiveness of the protective systems. Thus, the HAZOPS process identifies and qualitatively evaluates, where possible, potential accident scenarios that might occur in the facility.

The HAZOPS sessions can be well documented and the documents become a valuable record of how the facility will likely perform in response to process deviations caused by equipment failures, human errors, or external events. The potential accident scenarios and their causes are described and estimates of their consequences and likelihoods are recorded to the extent that they can be determined from experience or strictly qualitative analysis. Scenarios which require a more detailed analysis are referred for quantitative analysis in the next step of the hazard analysis.

1.1.4 Analysis of Consequences and Likelihood

Some accident scenarios which have been identified cannot be shown, on the basis of just a qualitative, perhaps very conservative, analysis, to have insignificant offsite and onsite consequences. These scenarios require a more precise and realistic quantitative analysis to determine if the consequences are actually a threat to the public or employees and if there is a need for further protection measures to be incorporated into the facility design. This may involve analysis of both offsite and onsite consequences and of the likelihood of the accident scenario occurring. Consequence analysis is usually the first quantitative analysis to be performed. If the offsite and onsite consequences can be shown to be of little concern, a quantitative analysis of the likelihood is unnecessary.

1.1.4.1 Analysis of Offsite Consequences. For an industrial facility the offsite consequences of most concern are usually the health effects associated with exposure to toxic gases, vapors, and mists released and dispersed from the facility to public or populated areas. In some cases a flammable vapor cloud can ignite after it has drifted away from the facility site and can produce thermal burns and possibly blast effects. Offsite consequence analysis involves determining

- The magnitude of release from loss of containment or from generation of toxic or flammable vapor or gas by evaporation, combustion in a fire, or unintended chemical reactions
- The dispersion of the toxic or flammable material to public areas and the concentrations in those areas
- The potential for an offsite deflagration of a cloud of flammable gases or vapors
- The population density in areas exposed to a toxic or flammable material
- The likely magnitude of human exposures
- The potential health effects from exposures to toxic material or ignited flammable vapor cloud.

Physical models are available for analyzing the generation and dispersion of vapors and gases under different atmospheric conditions. Health effects data for critical concentrations of most toxic materials are available for estimating the consequences.

1.1.4.2 Analysis of Onsite Consequences. The onsite consequences that are usually of most concern are exposures to toxic vapors, gases, or mists at the release site or elsewhere on the facility; thermal burns from fires; chemical burns from spills or explosions; blast effects of bursting vessel explosions; and blast effects and thermal burns resulting from vapor cloud explosions. Quantitative analysis of these consequences also requires physical models of spills; evaporation; fires and thermal radiation; explosions, fragment generation, and impact; and dispersion of vapors and gases. The models may differ from those used for offsite consequences because of the location and mobility of personnel with respect to the immediate site of the accident and the effects of buildings, vent systems, etc. Health effects data for burns and impacts as well as for short-term toxic exposures are available.

1.1.4.3 Analysis of Accident Scenario Likelihood. For some single-event accidents there are equipment failure rate data, human error probabilities, and external event frequencies that can be used directly to determine the probability of such an accident. More often, as was mentioned earlier, the accidents are sequences of several events, some causing the accident and some actuating protective systems or mitigating the impact of the accident. Each sequence has its own consequence with its own probability of producing that consequence. For these accident sequences or scenarios it is necessary to understand the relationship of each of the events to the accident and to each other. Fault tree analysis and event tree analysis are often used to illustrate and analyze complex scenarios. If the scenarios are not complex, fault tree and event tree construction can be bypassed and probability equations can be written directly and solved for the likelihoods of the accident scenarios.

Data or good estimates for the probability of the individual failure and error events that make up the accident are necessary inputs to the analysis. Failure rate data for common types of equipment and container materials are available from various sources. Human reliability data are not as readily available but there are techniques such as task analysis that can be used to provide good estimates of the likelihood of errors in performing particular operations and responding to particular emergencies.

1.1.5 Measures of Risk

Hazard analysis, as discussed above, can provide documentation of the potential accidents that might occur, a verbal description of the potential consequences of each of those accidents, and the likelihood that each of those accidents will occur, i.e., that the consequences will be realized. It is then necessary to express the risk in measures that are most suitable for the purposes of the analysis such as

- Make decisions on the use of resources to reduce the risk.
- Determine the acceptability of a site or choose among candidate sites.
- Inform interested parties -- regulatory agencies, the public, management, etc. -- of the risk of the facility or activity compared to other facilities and activities.

There are a variety of ways of expressing the risk of a facility, system, activity, etc. When the consequences can all be measured in monetary terms (e.g., gain or loss on investments, property damage from natural events, etc.) and the number of events/accidents is sufficiently large that statistical data and methods are valid, it is common to consider risk as the product of the consequences of the event and the likelihood of those consequences occurring; i.e., risk equals likelihood times consequences.

However, when the consequences involve effects on human health, safety, quality of life, etc. -- things that are difficult to measure in strictly monetary terms -- it is more useful to retain the verbal description of the consequences in the measure of risk. For example, the likelihood of an individual incurring irreversible health effects as a result of a particular accident at a frequency of 5×10^{-4} per year is a useful measure of the risk of that accident since there are frequency data for other accidental events and their consequences for comparison.

Depending upon the purpose of the hazard analysis it may be useful to express the risk in terms of risk to either an average or the most exposed individual, or to express the risk in terms of the risk to society, or both. Also, depending upon the purpose, it may be useful to describe the risk of individual accidents, or to describe the risk of the facility or activity as a whole, or both.

In choosing the most appropriate and useful measure of risk, it is very important to choose a measure that is easily communicated to all parties that will have an interest or concern about the risk. Logic, mathematics, and technical information are sufficient for the other steps of hazard analysis but communicating risk depends also on the receptivity, knowledge, values, etc., of the interested party and as such involves a subjectivity that must be taken seriously but not be allowed to interfere with the objectivity of the analysis.

1.2 OWMC Treatment Facility Background

The OWMC is a provincial Crown agency formally created in July 1981 by the Ontario Legislature. OWMC's primary responsibility is to establish and operate an industrial hazardous waste management system in Ontario (OWMC, 1984). OWMC has adopted the term "special waste" to mean industrial waste that cannot be treated by sewage treatment plants and/or municipal incinerators and should not be disposed of in municipal landfills (OWMC, 1982). Surveys of the amount of special waste generated in Ontario have led to a preliminary design for an OWMC Treatment Facility capable of treating 150,000 tonnes/annum (t/a) of organic (30,000 t/a) and inorganic (120,000 t/a) special wastes. Expandability by adding second and third work shifts and the flexibility to accommodate variations in both quantity and quality of the wastes are important design criteria. Hundreds of different wastes and waste mixtures are expected.

The preliminary design of the OWMC Treatment Facility, the subject of the hazard analysis, is an integrated design; all facilities for the treatment and disposal of organic and inorganic special wastes will be at one site. The design includes a buffer zone of 400 m between the "core zone" of the central operating area and the site boundary. There will be eight major areas of the OWMC Facility:

- Organic Tank Truck Unloading Area
- Inorganic Tank Truck Unloading Area
- Incinerator Tank Farm
- Physical/Chemical Storage Tank Area
- Incineration Plant
- Physical/Chemical Treatment Plant
- Solidification Plant
- Engineered Landfill

A brief description of each of the eight areas is given below. For additional information, "OWMC Treatment Facility - Design and Operations", prepared by Monenco, engineering consultant to OWMC, (OWMC, 1988b) should be consulted. A list of the piping and instrumentation diagrams (P&IDs), process flowsheets and layout drawings is given in Appendix A.

1.2.1 Organic and Inorganic Tank Truck Unloading Areas

The wastes will arrive in bulk in tank trucks of various sizes or in drums. Samples of the wastes will have been analyzed to characterize the waste in OWMC's onsite laboratory prior to shipment by the generator. On arrival at the facility the wastes will again be analyzed for verification before being sent to the appropriate unloading station. Organic liquids will generally be pumped from the truck to storage tanks located in the outdoor Incinerator Tank Farm. Inorganic liquids will be pumped to indoor storage tanks located at the Physical/Chemical Storage Tank Area. Dry solid organic wastes will go directly to bulk solid waste storage in the Incineration Plant. Dry solid inorganic wastes, and nonpumpable inorganic sludges, will be slurried for treatment in the unloading tank associated with the Physical/Chemical Treatment Plant or will be sent directly to the

Solidification Plant for size reduction and slurrying prior to physical/chemical treatment or for solidification if the materials are inert.

Some of the wastes will be delivered in drums. The drums may be pumped out with the contents going to the appropriate storage tank; the drums containing organic waste may sometimes be incinerated with their contents. Indoor storage will be provided in the Organic Drum Storage and Handling Building and the Physical/Chemical Storage Tank Area for approximately 1,000 drums of organic waste and 600 drums of inorganic waste, respectively.

1.2.2 Incinerator Tank Farm

The storage tanks in the Incinerator Tank Farm will be used for storage, separation, and blending of organic wastes. Different groups of tanks will be designated for specific types of organic wastes: halogenated solvents; aqueous organics; nonhalogenated solvents, oils, and sludges; and blended wastes. The tanks will be diked with the dikes sized to contain 100 percent of the volume of the largest tank in the group plus 10 percent of the volume of all the other tanks within the dike. The piping in the Incinerator Tank Farm will be designed to permit maximum interchangeability of wastes between tanks, but incompatible wastes will be kept segregated.

1.2.3 Physical/Chemical Storage Tank Area

The storage tanks in the Physical/Chemical Storage Tank Area will be grouped to handle acidic inorganic wastes, neutral/alkaline inorganic wastes, and aqueous organic wastes requiring separation of the organic waste. Waste tank configurations will allow either phase separation or mixing of wastes. Piping will be designed to allow maximum interchangeability of wastes between groups of tanks, but incompatible wastes will be kept segregated.

1.2.4 Incineration Plant

The Incineration Plant will have a waste feed system, a rotary kiln, and a secondary combustion chamber plus other equipment such as combustion air fans, waste heat recovery boiler, spray dryer, electrostatic precipitator, gas scrubber, induced draft fan and stack. Wastes will be fed to the incinerator as follows:

- Liquid wastes through burner nozzles or lances
- Pumpable sludges through lances
- Drums by conveyor to the rotary kiln feed chute
- Dry bulk solids by an overhead crane to the rotary kiln feed chute.

The Incinerator is sized to handle an average waste feed rate of 4,280 kg/h when operating at about 90 percent of its design capacity. The nominal design thermal capacity of the Incinerator will be about 67 x 10^6 kJ/h. Wide variations in waste characteristics and heating values are expected, but blending wastes with different heating values, using waste oils as support fuel, and other practices can be used to accommodate the waste variations.

Flue gas treatment will be used to reduce contaminants in the form of particulates, acid gases, and heavy metals. Trace organics are reduced by a combination of the combustion process and the flue gas treatment system. The stack height will be confirmed through computer modeling studies of flue gas dispersion taking into account physical, topographical, and climatic conditions particular to the selected site to ensure that the concentrations of contaminants offsite are well below the permissible levels in the Regulations.

1.2.5 Physical/Chemical Treatment Plant

The Physical/Chemical Treatment Plant includes three distinct process treatment systems designed for treating the following three waste categories:

- Inorganic waste (batch treatment)
- Aqueous organic waste (batch treatment)
- Miscellaneous wastes generated onsite (continuous treatment).

Basically, the treatment systems contain the following fundamental stages of storage and treatment

	Inorganic	Aqueous Organic	Miscellaneous
• Initial storage	x	x	x
• Primary treatment	x	x	
• Secondary treatment	x	x	x
• Intermediate storage	x	x	
• Polishing	x	x	x
• Final storage	x	x	x
• Evaporation	x		x

Primary treatments include phase separation, dissolution or slurrying, and blending and/or equalization to prepare the waste for subsequent treatment. Secondary treatments such as chemical oxidation and reduction, neutralization, and precipitation and several physical treatments are designed to destroy, stabilize, and/or concentrate toxic contaminants. Polishing removes residual contaminants in the effluent.

To operate the series of treatments required for a specific waste demands a large number of interconnections among tanks and equipment. This results in an intricate pattern of piping, valves, and pumps to permit movement of the waste from one treatment stage to another.

1.2.6 Solidification Plant

The Solidification Plant will contain two separate solidification processes which allows for flexibility when dealing with the variations in solids content of waste delivered to the plant. The Low-Solids Process uses an "in-line" mixing system to combine the liquids to be treated with cement and sodium silicate. The High-Solids Process uses a "batch" system where the materials to be treated (wastes and waste residues), cement, additives, and required make-up liquids are combined in a mixer, mixed, and then discharged in the form of a paste which becomes solid when cured.

1.2.7 Engineered Landfill

The Engineered Landfill will receive the material solidified in the Solidification Plant. No untreated wastes or liquids will be disposed of in the Engineered Landfill unless they have been determined to be inert before solidification. The Engineered Landfill will be located in the area between the central operating area and OWMC's property boundary. A perimeter security fence will surround the entire landfill area and a 50-m wide (minimum) buffer zone will be left between the property boundary and the Engineered Landfill.

1.2.8 Instrumentation and Process Controls

The following is a description of instrumentation and process controls planned for use at the OWMC Facility. There will be two control rooms, one for the organic area and one for the inorganic area. The technologies to be used for the process instrumentation include electronic transmitters and digital programmable control. The control of movement of material is of primary concern. While some of the treatment stages require manual operations, it is intended to have as much centralized coordination as possible. The type of actions required from the operator are operation of pumps and valves, handling of alarms, and performing certain shutdown actions. Valve lineups are shown to the operators by the digital process control system via cathode-ray-tube displays (CRTs). Alarms will be annunciated and shown on the CRTs. In addition, some critical alarms will be hardwired. Some of the organic treatment sections of the facility operate 24 hours a day, 7 days a week. The inorganic sections will be operated on one or more shifts per day, 5 days a week. Alarms from sensors in the inorganic sections that could occur while that section is not in active use will be annunciated in the Incinerator Control Room. Pumps operated from the control room will have limited local control in the tank farm so as to allow the pump to be turned off locally. Because of the wide variety of materials to be handled, a majority of the analysis will be done on samples in the Physical/Chemical Treatment Plant laboratory rather than by on-line instruments.

There will be one or two operators in each control room when that section of the plant is in operation, as well as several local operators. The laboratory will be staffed with approximately 31 people. There will always be at least one operator in the Incinerator Control Room, and one in the Physical/Chemical Control Room if waste is being processed in that section.

The data management system will store the waste characterization data, treatment recipe, record of waste management, treatments currently being done, posttreatment records, facility inventory, and data on previous waste shipments by a particular company.

Pneumatic valves, which can be configured to fail in a safe position, will be used. Limit switches will be used for monitoring where the position of the valve is critical.

Preshipment samples of wastes to be treated will be fully analyzed before the waste is received. Procedures for handling and treating that waste can be established before the waste is received. A limited analysis will be performed onsite, when the waste is received, to verify that it is the waste that was previously analyzed. OWMC has responsibility for the waste as soon as it is received.

2.0 OWMC TREATMENT FACILITY HAZARD ANALYSIS

The OWMC Treatment Facility Hazard Analysis involved the following interrelated tasks:

1. Identification and Qualitative Evaluation of Potential Accident Scenarios
    a) Identification of Types of Hazards/Consequences and Accidents of Concern
    b) Development of Qualitative Decision Criteria for Screening Accident Scenarios
    c) Identification and Qualitative Screening of Accident Scenarios
2. Quantitative Analysis of Consequences of Accident Scenarios
    a) Specification of Typical Wastes for Consequence Analysis of Accident Scenarios
    b) Grouping and Coding Accident Scenarios for Consequence Analysis
    c) Quantitative Analysis of Consequences
3. Quantitative Evaluation of Likelihoods of Accident Scenarios with Significant Consequences
4. External Events Analysis
5. Estimation of Facility Risk.

Figure 2-1, Hazard Analysis Tasks, shows how these tasks are related to each other and to other supplementary or preparatory tasks. The following sections of this report describe each of these tasks as they were performed for the OWMC Hazard Analysis.

2.1 Identification and Qualitative Evaluation of Potential Accident Scenarios

The Hazard and Operability Study (HAZOPS) method was used in the OWMC Treatment Facility Hazard Analysis to identify potential accidents that might occur at the facility and qualitatively evaluate their consequences and likelihood. In the process of doing this the HAZOPS method also

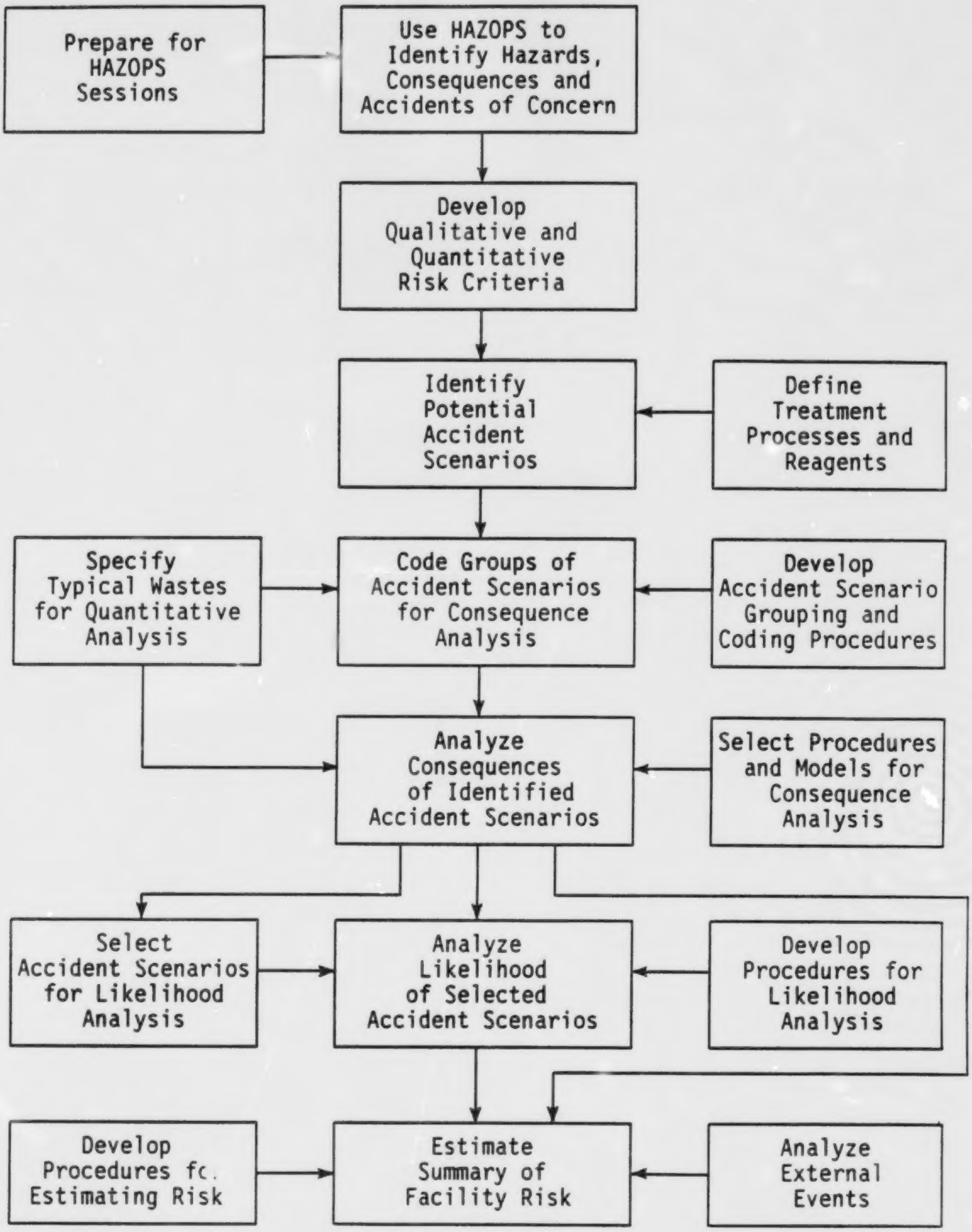

Prepare for HAZOPS Sessions
Use HAZOPS to Identify Hazards, Consequences and Accidents of Concern
Develop Qualitative and Quantitative Risk Criteria
Identify Potential Accident Scenarios
Define Treatment Processes and Reagents
Specify Typical Wastes for Quantitative Analysis
Code Groups of Accident Scenarios for Consequence Analysis
Develop Accident Scenario Grouping and Coding Procedures
Analyze Consequences of Identified Accident Scenarios
Select Procedures and Models for Consequence Analysis
Select Accident Scenarios for Likelihood Analysis
Analyze Likelihood of Selected Accident Scenarios
Develop Procedures for Likelihood Analysis
Develop Procedures fc. Estimating Risk
Estimate Summary of Facility Risk
Analyze External Events

FIGURE 2-1. HAZARD ANALYSIS TASKS

provides an opportunity to suggest additional prevention and mitigation measures where needed and to screen out those scenarios that do not have hazardous consequences. The remaining scenarios are retained for more quantitative evaluation of consequences, likelihood, and risk.

The HAZOPS method was chosen for the identification of potential accidents because it is highly structured and very thorough. It is especially suited to examining a new facility design where there has been little past experience related to accidents to refer to for identifying potential accidents and their effects.

The OWMC Facility HAZOPS were performed with two teams, each of which included several of the OWMC Facility design staff and management, a representative of OWMC who will have operating responsibilities, contractors involved in the OWMC Risk Assessment, and several Battelle staff. A Battelle staff member experienced in the HAZOPS method led each HAZOPS session. With these members, each team had knowledge of the details of design and proposed operation of the specific facility plus broad experience in risk assessment and hazard analysis of chemical process facilities and other engineered systems.

The first task for the HAZOPS team was to identify the types of hazards/consequences and types of potential accidents that would be of concern for a facility such as the OWMC Treatment Facility. The second task was to develop screening criteria to aid in judging the risk of the accident scenarios identified by the HAZOPS teams. The final task was to conduct the HAZOPS -- systematically examine the facility; identify the accident scenarios that might be of concern; and qualitatively and very conservatively screen those scenarios to determine which scenarios could be dismissed from further consideration and which would require a more detailed, quantitative analysis of consequences or likelihood.

2.1.1 Identification of Types of Hazards and Potential Accidents of Concern

The first task for the HAZOPS team was to identify the types of hazards and the types of accidents that should be considered in the hazard analysis.

2.1.1.1 Types of Hazards of Concern. A list of general chemical process plant hazards that might apply to the OWMC Facility was prepared by Battelle and discussed with the HAZOPS team. The different types of process hazards that were considered in the hazard analysis, and their possible offsite and onsite effects, are presented in Table 2-1. Some process hazards that are not expected to be encountered in the operation of the OWMC Facility are also presented. Other types of non-process-related hazards that were specifically excluded from the hazard analysis are presented in Tables 2-2 and 2-3.

2.1.1.2 Types of Accidents of Concern. The following types of accidents that might cause acute offsite and/or onsite health effects were identified by Monenco Ltd., engineering consultants to OWMC, and the HAZOPS teams:

- Spill or leak of liquid waste followed by evaporation and dispersion of toxic waste component
- Spill or leak of liquid waste followed by a fire with entrainment and dispersion of toxic chemical in the waste
- Spill or leak of liquid waste followed by a fire with generation and dispersion of toxic products of complete combustion or incomplete combustion
- Spill or leak of liquid waste followed by a fire with boiling, vaporization, and dispersion of waste remaining in that tank or in an adjoining tank
- Mixing of incompatible wastes followed by venting and dispersion of toxic reaction product
- Mixing of incompatible wastes followed by bursting of tank or pipe and release of liquid wastes (see above liquid spills)
- Explosion of tank or pipe (hydraulic or thermal overpressure) with release of liquid wastes (see above liquid spills)
- Release and dispersion of toxic fumes from Incinerator from a leak or component failure.

The principal offsite hazard of each type of accident is the release and transport of toxic vapors, gases, aerosols, or particles to a populated area. The principal onsite effects, in addition to the toxic effects, would

TABLE 2-1. WORKING LIST OF ACUTE PROCESS HAZARDS

Hazard	Examples	Possible Effects Offsite	 Onsite
I. BLAST EFFECTS OF EXPLOSIONS			
A. Bursting vessel explosion	Overpressurization; internal deflagration	X	X
B. Confined-area deflagration	Dispersed vapor/dust/mist ignited inside enclosure	X	X
C. Condensed-phase detonation	Nitrocellulose; peroxides	X	X
D. Implosion	Pumped-out tank	-	X
II. THERMAL/RADIATION EXPOSURE			
A. Fire (deflagration)	Pool fire; flash fire	X	X
B. Hot material release	Steam leak	-	X
III. REACTIVE CHEMICALS EXPOSURE			
A. Toxic vapor release	Vapor/mist/dust inhaled	X	X
B. Chemical burns	Acid splashed on skin	X	X
C. Skin absorption	Systemic toxic effects	-	X
D. Oral/ingestion	Internal toxic effects	-	X
IV. ASPHYXIATION	Inerted vessel entry	-	X
V. OTHER EFFECTS POTENTIALLY NOTICEABLE TO OFFSITE POPULATION			
A. Odor	Mercaptans, amines, etc.	X	X
B. Mist/fog/plume	Titanium dioxide, etc.	X	X
C. Noise	Explosion	X	X
D. Flames	Outside fire	X	X
VI. PROCESS HAZARDS NOT EXPECTED TO BE ENCOUNTERED DURING STUDY			
A. Rapid phase transition	Boiling-liquid-expanding-vapor explosion		
B. Vapor cloud explosion	Massive unconfined vapor cloud ignited		
C. Cryogenic material release	Refrigerated brine		
D. Nuclear radiation	Level instrumentation; nuclear waste		

TABLE 2-2. OCCUPATIONAL HAZARDS

The following non-process-related occupational hazards were not addressed in the OWMC Hazard Analysis. A checklist/what-if review will be conducted separately to ensure these onsite hazards are adequately controlled in the site's overall occupational safety and health program.

A.	Electrical	Contact with live wire; lightning	
B.	Falling objects	Cranes,structural,maintenance,etc.	
C.	Rotating equipment	Motors, conveyors, agitators, etc.	
D.	Moving equipment	Forklifts, trucks, drum dumping, etc.	
E.	Hot surface contact	Heated line/vessel	
F.	Cryogenic surface contact	Cold brine piping	(Not expected)
G.	Electromagnetic radiation	Lasers, microwaves	(Not expected)
H.	Nonprocess deflagration	Building fires	
I.	Nonprocess pressure/flow	Water lances, compressed air	
J.	Nonprocess explosion	Compressed air cylinders/tanks	
K.	Cuts/lacerations	Sharp objects, head clearance	
L.	Drowning	Sumps, ponds, flooding	

TABLE 2-3. CHRONIC HAZARDS

The following chronic hazards, since they are not acute risk contributors, were not included in the OWMC Hazard Analysis and will need to be addressed in the site occupational safety and health program.

A.	Chronic chemical exposure	Carcinogen/mutagen/teratogen effect and a variety of other effects
B.	Noise	Loud machinery/process
C.	Heat stress	Work near hot surfaces

Runoff into surface water or seepage into groundwater following a leak of process material does not generally present an immediate acute hazard and is outside the scope of the OWMC Hazard Analysis.

be chemical burns from spilled liquid waste or thermal burns if the spilled waste was flammable and was ignited. Onsite effects of an explosion might include chemical burns from spattered waste and injuries from projectiles from the bursting vessel.

In each of these accident types the cause, consequences, and likelihood of the accident may depend not only upon the design and operation of the facility but also upon the toxicity and the chemical and physical properties of the chemicals/contaminants in the wastes involved. This is discussed in detail in subsequent sections of this report.

2.1.2 Development of Decision Criteria

Decision criteria were developed for initial qualitative evaluation of accident scenarios as they were identified in the HAZOPS sessions and for final evaluation of both individual accident scenarios which have required quantitative analysis of their consequences and likelihood and a summary of facility risk. However, in the OWMC Hazard Analysis very little evaluation was attempted during the HAZOPS sessions. Evaluation would have required a prohibitive expenditure of time in the sessions because of the large number of wastes and waste contaminants that may be received at the facility and in most cases each accident scenario that was identified would have had to be evaluated for several waste contaminants. For that reason little screening was possible in the HAZOPS sessions and all accident scenarios that were identified were recorded.

2.1.3 Identification and Qualitative Screening of Potential Accident Scenarios

The HAZOPS teams examined the facility using process flowsheets, piping and instrumention diagrams, and engineering drawings and outlines of operating procedures. Figure 2-2 shows the steps of the HAZOPS procedure. The HAZOPS teams looked at one line, vessel, subsystem, or operation step at a time. A predetermined set of guide words was applied to each of the process parameters (flow rate, temperature, pressure, etc.) at that point in the process to identify potential deviations from the operational intent (for that process parameter) which might lead to an accident. When a potential accident was identified which might be expected to have significant consequences, changes which might prevent or minimize the consequences or reduce the likelihood of the accident were considered. When questions were raised which could not be answered quickly during the HAZOPS session, they were referred to someone for special study outside of the session and before the next session, whenever possible, so that the results could be used in the next session.

Table 2-4 lists the guide words that were used in the HAZOPS, with examples of their meanings. Table 2-5 lists possible deviations of the process parameters, as indicated by application of the guide words, that were examined by the HAZOPS teams for their effect on the process and plant safety. An example of the HAZOPS procedure and documentation is described in Appendix B.

2.1.3.1 Schedule and Participants of HAZOPS Sessions. A schedule of 21 HAZOPS sessions, usually of 3 days each, was needed to examine the entire OWMC Treatment Facility. Two HAZOPS teams were used, one for the facility areas principally involved with organic wastes and the other for areas principally involved with inorganic wastes. In addition, the Inorganic Team was responsible for the Solidification Plant and the Organic Team was responsible for the Engineered Landfill.

The basic HAZOPS teams were made up of three staff members from Monenco and three from Battelle. Monenco staff provided the knowledge of the overall facility design and operation, i.e., the detailed design, the planned operating procedures, and the design of the instrumentation and controls for the particular facility area being studied at that time. Battelle provided the experienced HAZOPS leader, a specialist in human reliability, and a chemical engineer with broad knowledge of the technology involved. Battelle was responsible for recording the information developed in the HAZOPS sessions.

The OWMC Process Design Coordinator participated in a majority of the meetings to provide input on the treatment and operating philosophy of the OWMC Facility. Additional Monenco staff participated as needed. A representative of Von Roll, incineration technology consultant to OWMC, and

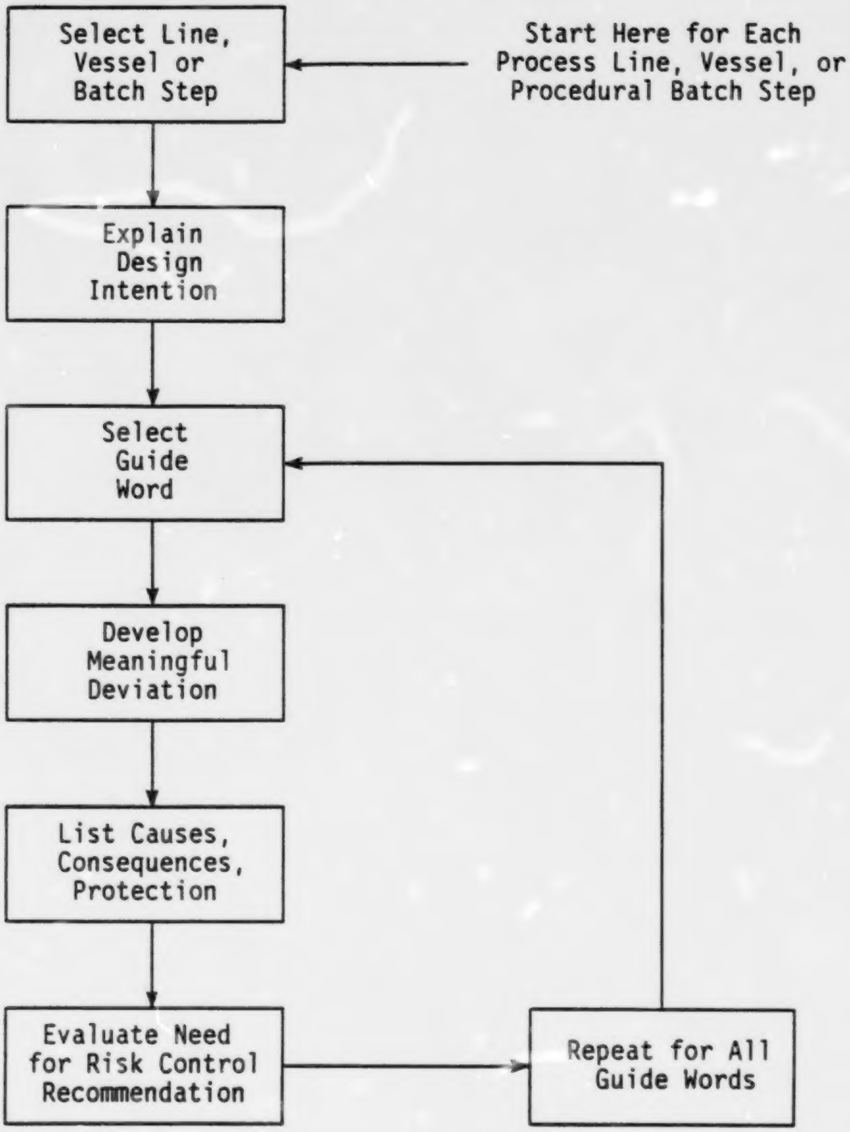

Select Line, Vessel or Batch Step
Start Here for Each Process Line, Vessel, or Procedural Batch Step
Explain Design Intention
Select Guide Word
Develop Meaningful Deviation
List Causes, Consequences, Protection
Evaluate Need for Risk Control Recommendation
Repeat for All Guide Words

FIGURE 2-2. GENERAL HAZOPS PROCEDURE

TABLE 2-4. HAZOPS GUIDE WORDS

Guide Word	Meaning	Example
None	Negation of intention	No forward flow when there should be Sequential process step omitted
More of	Quantitative increase	More of any relevant physical parameter than there should be, e.g. more flow (rate, quantity), more pressure or dP, higher temperature, higher viscosity Batch step allowed to proceed for too long a time
Less of	Quantitative decrease	Opposite to "MORE OF"
Part of	Qualitative decrease	System composition different from what it should be (in multicomponent stream)
As well as	Qualitative increase	More things present than should be, e.g. extra phases, impurities Transfer from more than one source or to more than one destination
Reverse	Logical opposite	Reverse flow Sequential process steps performed in reverse order
Other	Complete substitution	What may happen other than normal continuous operation, e.g., start-up, normal shutdown, emergency shutdown, maintenance/cleanout, testing Transfer from wrong source or to wrong destination or wrong material is added

TABLE 2-5 HAZOPS DEVIATIONS

Design Variable	Deviation	Design Variable	Deviation
Flow (rate)	No flow High flow Low flow Reverse flow	Time	Too long Too short Too late Too soon
Flow (quantity)	Too much Too little	Location	Additional source Additional destination Wrong source Wrong destination
Pressure	High pressure Low pressure/ vacuum		
Sequence	Misses a step Steps reversed Extra step	Temperature	High temperature Low temperature
Level	High level/ overflow Low level/ empty	pH	High pH Low pH
		Viscosity	High viscosity Low viscosity
Mixing	Too much mixing Not enough mixing Loss of agitation Reverse mixing	Heat value	High heat value Low heat value
		Flash point	High flash point Low flash point
Composition	Component missing High concentration Low concentration Diluted	Phases	Extra phase Phase missing
Purity	Impurities present Catalyst deactivated		

a representative of Hessische Industriemüll GmbH (HIM), operators of a facility similar to the proposed OWMC Facility, participated in two 2-day sessions on the Incineration Plant. Another representative of HIM participated in a 1-week session on the Physical/Chemical Treatment Plant.

2.1.3.2 Identification of Potential Accident Scenarios. Because the facility design is only preliminary, considerable time was spent in the HAZOPS sessions in resolving design details and refining operating procedures for the area being examined before the actual HAZOPS process could begin. It was clear that there would not be sufficient time in the actual HAZOPS sessions to examine all equipment and all operations in each area of the facility with all candidate wastes. Therefore, the HAZOPS sessions focused on completing the examination of one set of operations in each area to identify the different types of accident scenarios that might occur in that area. The results of that examination were used later, after the HAZOPS sessions, as a template for examining other identical or very similar operations in the same area which were not examined in depth within the HAZOPS sessions. In this way, all operations that have a potential for accidents that could be of concern were examined in an efficient and thorough manner. About 10,000 potential accident scenarios were identified, either in the actual HAZOPS sessions or in the templating which followed. This is considered a very positive indication of the thoroughness of the hazard identification process.

2.1.3.3 Qualitative Evaluation of Accident Scenarios. The OWMC Waste Characterization Data Base (Canviro, 1985) identified hundreds of possible chemicals and chemical mixtures that might be present in the wastes that could be sent to the OWMC Facility for treatment. This large number of possible chemicals and the large number of accident scenarios made it impractical to do a qualitative screening of the consequences of each combination of accident scenario and possible waste chemical during the actual HAZOPS sessions. Therefore, all of the accident scenarios identified were recorded. Most were scheduled for quantitative analysis of the potential consequences although some were tabled by the HAZOPS team when no hazardous consequence from the scenario or no plausible cause of the scenario was identified. For example, one scenario that involved freezing and rupture of a pipe was eliminated because it would have required a temperature at the site of -57°C for an extended period of time for the rupture to occur.

2.2 Quantitative Evaluation of Consequences of Accident Scenarios

The quantitative consequence analysis was a screening analysis to identify the accident scenarios that might have unacceptable consequences. A quantitative analysis was performed but conservative values for many parameters were used to simplify the analysis. This approach resulted in a conservative evaluation; i.e., the accident scenarios which clearly do not have any significant consequences were screened out from further consideration while the accident scenarios remaining might or might not have significant consequences.

Hundreds of different wastes and waste mixtures, as identified in the OWMC Waste Characterization Data Base (Canviro, 1984), may be sent to the OWMC Facility for treatment. With nearly 10,000 different accident scenarios to be evaluated, it was impossible to analyze all combinations of scenarios and waste/waste mixtures. Therefore, a typical waste was developed for each waste category that was considered "typical" of the wastes in that category. The typical wastes were then used to represent the actual waste streams in the quantitative consequence analyses of each category.

This is a reasonable approach to obtain consequence results for a summary of facility risk. It also provides good results for screening out the accident scenarios which will not have significant consequences and do not need further attention. However, it is recognized that the typical wastes are not necessarily the wastes which will produce the maximum consequences for a given scenario.

2.2.1 Specification of Wastes for Consequence Analysis of Accident Scenarios

2.2.1.1 Categories of Waste in Different Areas of Facility. For purposes of identifying which different categories of industrial waste are expected to be present in each of the different areas of the facility, the OWMC Treatment Facility can be considered to be made up of six different areas for receiving, storage, and treatment of industrial wastes. Following this in the sequence of process steps are two more areas, the Solidification Plant and the Engineered Landfill, where the waste has been detoxified and has much less potential for causing acute exposures as a result of accidents. The six different receiving, storage, and treatment areas, and the categories of waste that will be handled in each, are shown in Table 2-6.

2.2.1.2 Development of Typical Wastes. A typical waste was developed to represent each category of waste in the OWMC Waste Characterization Data Base. The approach, achieved by consensus of the hazard analysis participants, is described below.

1. The waste streams were organized into different categories of waste based on waste characteristics and handling methods, storage areas and treatment processes as was described in Section 2.2.1.1.

2. The waste streams in each waste category were ranked by the amount of the waste expected to be received and treated at the OWMC Facility.

3. Waste streams were selected, starting at the top of the list, for each category such that the following criteria were met:

   a) The total amount of waste represented by the selected waste streams was at least 50 percent of the total amount of all the waste streams in that category. However, no waste streams were included if their contribution to the total for that category was less than 2 percent. (Due to this restriction the total amount of the selected waste streams was only 47.5 percent and 47.9 percent of the total amount for two of the categories. See Appendix C for details on the typical wastes.)

TABLE 2-6. WASTE CATEGORIES IN SPECIFIC AREAS OF FACILITY

Operating Area of Facility	Waste Categories								
	AO	HW	WS	ON	NA	AC	CY	CH	IN
(OR) - Organic Receiving Areas	X	X	X	X					
(OS) - Incinerator Tank Farm	X	X	X	X					
(OT) - Incinerator	X	X	X	X					
(IR) - Inorganic Receiving Area					X	X	X	X	X
(IS) - Physical/Chemical Plant Storage Tanks	X				X	X	X	X	X
(IT) - Physical/Chemical Treatment Plant	X*				X	X	X	X	X

Waste Category Abbreviations Used in Hazard Analysis:

AO	Aqueous Organic Wastes
HW	Organic Halogenated Solvents
WS	Organic NonHalogenated Solvents, Oils, and Sludges
ON	Organic Nonpumpable Wastes

NA	Inorganic Neutral/Alkaline Wastes
AC	Inorganic Acidic Wastes
CY	Cyanide Wastes
CH	Chromate Wastes
IN	Inorganic Nonpumpable Wastes

---

* Organic components of AO will be removed before treatment in the Physical/Chemical Treatment Plant.

   b) At least five streams were selected for each waste category even if this produced a total amount significantly above 50 percent of the total amount of waste in that category.

3. The contaminants and their concentrations in the selected waste streams were identified.

4. Typical wastes, which include all contaminants that appear in any of the contributing waste streams, were developed for each waste category. In the typical waste, the concentration of each contaminant is equal to the sum of its concentration in each contributing waste stream prorated, in each case, by the amount of that waste stream that is expected at the facility compared to the total amount expected from all waste streams represented in that typical waste.

It is apparent that this method of developing typical wastes may produce a typical waste that is less hazardous than an equal amount of one or more of its contributors. This is because, in effect, the contributor is significantly diluted by the other constituents of the typical waste when the frequency of receipt of the contributor is small. While this does not invalidate the estimation of facility risk (where the frequency of receipt of each contributor is also taken into account), it may understate the maximum consequences of a particular accident scenario.

2.2.1.3 Composition of Typical Wastes Specified.

The compositions of the typical wastes that were developed for each category are detailed in Appendix C.

2.2.2 Grouping and Coding Accident Scenarios for Consequence Analysis

2.2.2.1 Types of Accident Scenarios to be Analyzed.

Figure 2-3, Consequence Analysis Trees, presents the successive events of different types of accident scenarios, starting with the initial accidental events that have been identified for the OWMC Treatment Facility. These are the possible events to be analyzed to quantify the consequences of each of the accident scenarios. The consequences also depend upon which wastes are involved and several parameters related to the initial accident event (e.g., size of spill, area of dike surrounding the spill, etc.) that are in the

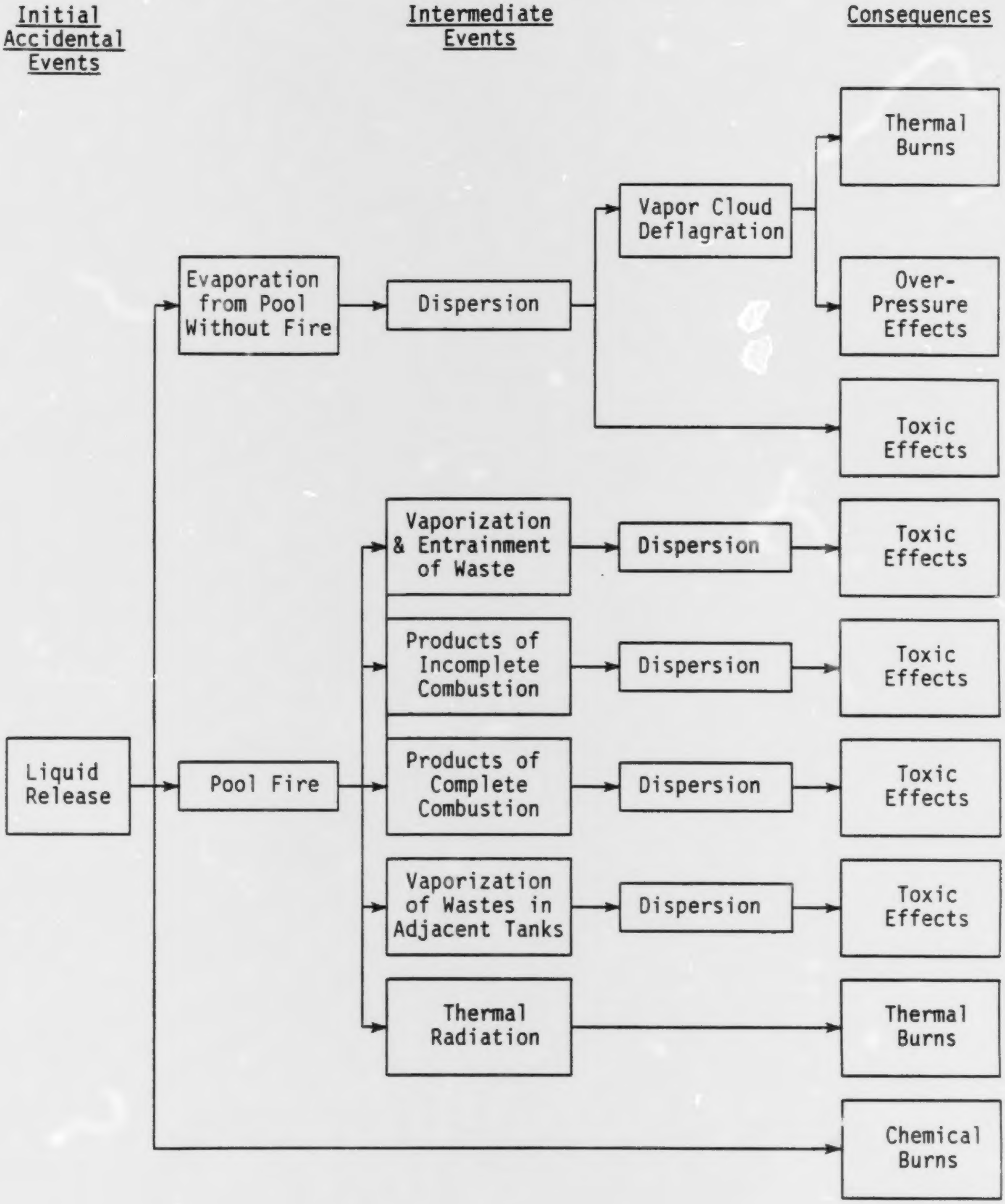

Initial Accidental Events
Intermediate Events
Consequences
Liquid Release
Evaporation from Pool Without Fire
Dispersion
Vapor Cloud Deflagration
Thermal Burns
Over-Pressure Effects
Toxic Effects
Pool Fire
Vaporization & Entrainment of Waste
Dispersion
Toxic Effects
Products of Incomplete Combustion
Dispersion
Toxic Effects
Products of Complete Combustion
Dispersion
Toxic Effects
Vaporization of Wastes in Adjacent Tanks
Dispersion
Toxic Effects
Thermal Radiation
Thermal Burns
Chemical Burns

FIGURE 2-3. CONSEQUENCE ANALYSIS TREES

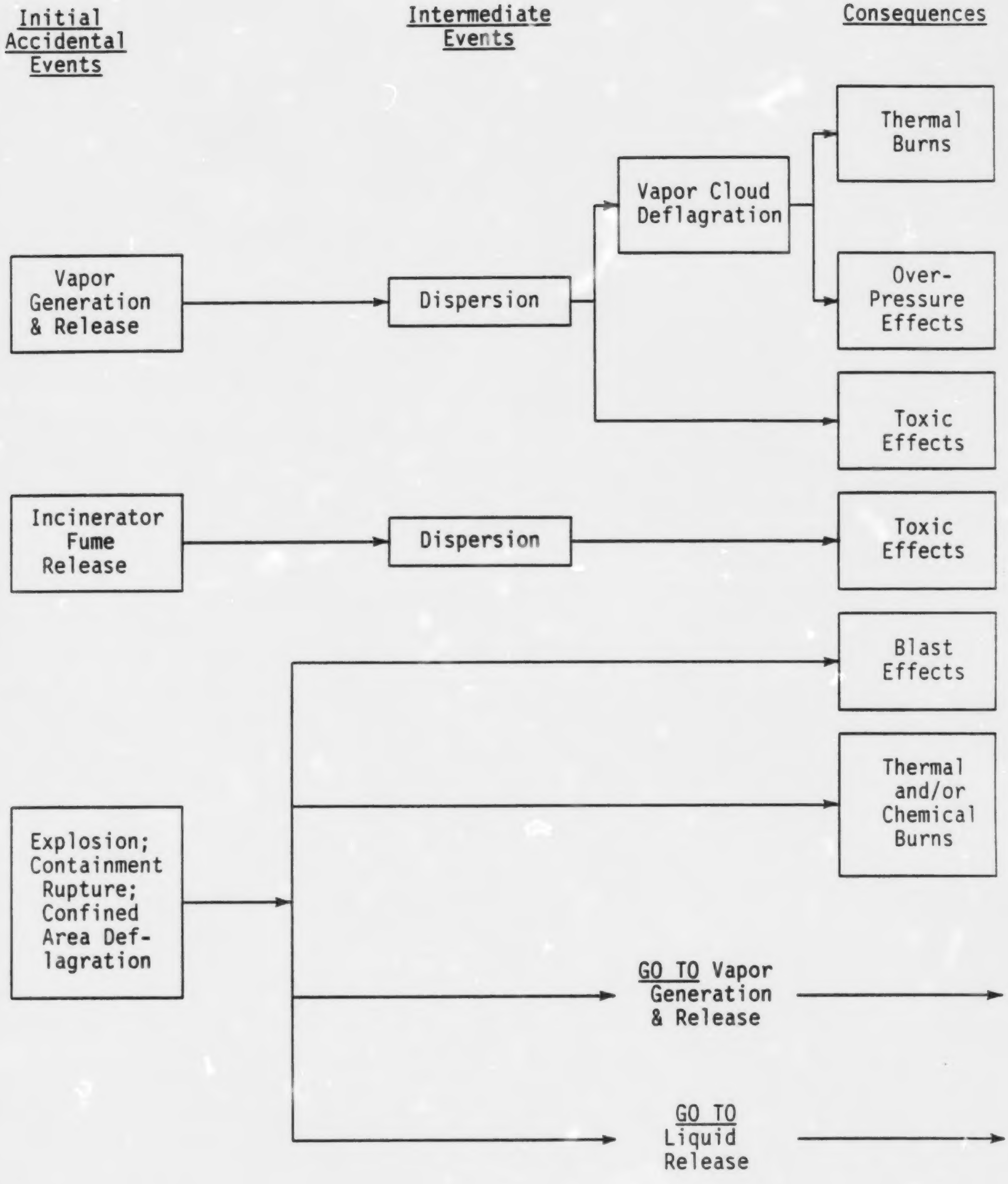

Initial Accidental Events
Intermediate Events
Consequences
Vapor Generation & Release
Dispersion
Vapor Cloud Deflagration
Thermal Burns
Over-Pressure Effects
Toxic Effects
Incinerator Fume Release
Dispersion
Toxic Effects
Blast Effects
Thermal and/or Chemical Burns
Explosion; Containment Rupture; Confined Area Deflagration
GO TO Vapor Generation & Release
GO TO Liquid Release

FIGURE 2-3. (Continued)

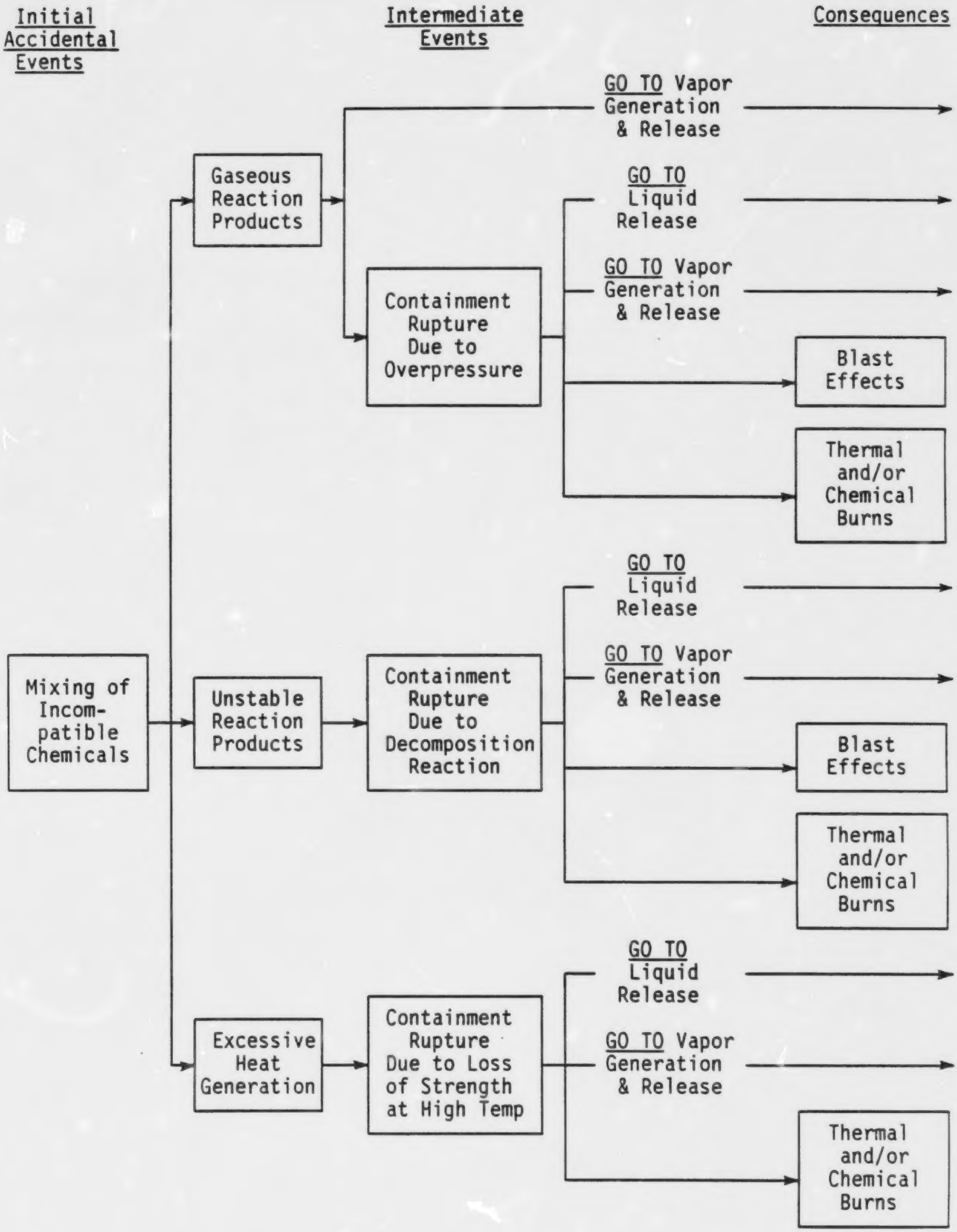

Initial Accidental Events
Intermediate Events
Consequences
Mixing of Incom-patible Chemicals
Gaseous Reaction Products
Unstable Reaction Products
Excessive Heat Generation
Containment Rupture Due to Overpressure
Containment Rupture Due to Decomposition Reaction
Containment Rupture Due to Loss of Strength at High Temp
GO TO Vapor Generation & Release
GO TO Liquid Release
GO TO Vapor Generation & Release
Blast Effects
Thermal and/or Chemical Burns
GO TO Liquid Release
GO TO Vapor Generation & Release
Blast Effects
Thermal and/or Chemical Burns
GO TO Liquid Release
GO TO Vapor Generation & Release
Thermal and/or Chemical Burns

FIGURE 2-3. (Continued)

accident scenario consequence code described in the next section. Figure 2-3 is an elaboration on the types of accidents described in Section 2.1.1.2 and was developed to identify each event of each type of accident scenario for the consequence analysis.

Judgment was used to determine which consequences were evaluated quantitatively for each initial accident event. For example, the "overpressure effects" consequence for the liquid release event would only result from a vapor cloud deflagration of a massive quantity of flammable vapors, causing an unconfined vapor cloud explosion. Since large quantities of highly volatile, flammable materials (such as butane) will not be handled onsite, it was not necessary to calculate the overpressure effects of vapor cloud deflagrations following liquid spills. However, the "thermal burns" consequence was considered as a possible consequence for these accident scenarios, and was quantitatively assessed.

2.2.2.2 Accident Scenario Grouping/Coding. To facilitate the consequence analysis, all accident scenarios that would be expected to have the same consequences were given the same accident scenario code and analyzed as a group. For example, there are several ways in which a leak or spill of a particular waste might occur in a particular area. For all of those cases, for a given waste, where the spill is the same, the duration of the release is the same, and the temperature of the waste is the same, the consequences can be expected to be the same regardless of how the leak or spill occurred. Although each different way that the leak or spill might occur is represented by a different accident scenario, and may have a different probability of occurring, for the consequence analysis they can all be represented by the same code, e.g., L-AO-C-75-2-A, where

L is the type of accident -- liquid spill

AO is the category of waste -- aqueous organic

C is the size of release -- 0.5 m^3

75 is the spill area -- 75 m^2

2 is the duration of release -- 10 min

A is the temperature of the waste -- ambient.

Figure 2-4 illustrates how several accident scenarios are represented by one accident scenario code. In this case, four accident scenarios are represented by one accident scenario code and six by another. Actually, in this instance each of the ten accident scenarios may involve any of three different categories of waste. Thus, the six accident scenario codes actually represent 30 accident scenarios when the three waste categories are considered.

The complete procedure for coding the accident scenarios for consequence analysis is described in Appendix D.

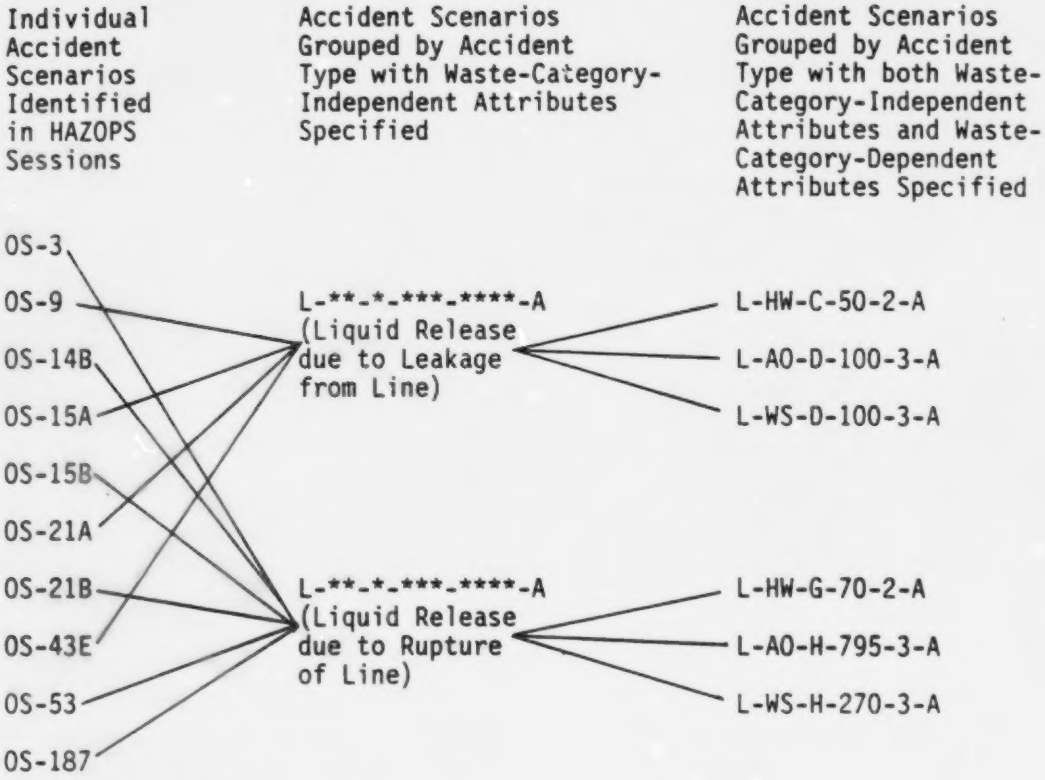
2.2.3 Quantitative Evaluation of Consequences

Methods of analysis for the different accident events and consequences diagrammed in Figure 2-3 were selected or developed. They were then used to evaluate the consequences of the accident scenarios identified in the HAZOPS sessions. Groups of accident scenarios with the same accident scenario code were analyzed as a group. The methods used in the analyses are described in detail in Appendix E.

2.3 Quantitative Evaluation of Likelihoods of Accident Scenarios with Significant Consequences

For single event accidents there are failure rate data, human error probabilities, and external event frequencies that can be used directly to determine the likelihood of such an accident. More often, as was mentioned earlier, the accidents are sequences of several events, some initiating or propagating the accident and some acting to prevent or inhibit the accident. For these accident sequences or scenarios it is necessary to understand the relationship of each of the events to the accident and to each other so that probability equations can be written and solved for the likelihood of the entire accident sequence.

Data or good estimates for the probability of the individual failure and error events that make up the accident are necessary inputs to the analysis. Failure rate data for common types of equipment and container materials are available from various sources. Human reliability data are


Individual Accident Scenarios Identified in HAZOPS Sessions
Accident Scenarios Grouped by Accident Type with Waste-Category-Independent Attributes Specified
Accident Scenarios Grouped by Accident Type with both Waste-Category-Independent Attributes and Waste-Category-Dependent Attributes Specified
OS-3
OS-9
OS-14B
OS-15A
OS-15B
OS-21A
OS-21B
OS-43E
OS-53
OS-187
L-**-*-***-****-A (Liquid Release due to Leakage from Line)
L-**-*-***-****-A (Liquid Release due to Rupture of Line)
L-HW-C-50-2-A
L-AO-D-100-3-A
L-WS-D-100-3-A
L-HW-G-70-2-A
L-AO-H-795-3-A
L-WS-H-270-3-A

Notes:

1. * is a wild card for the size of release. This can vary with the waste category because of the different tank sizes for different waste categories.
2. ** is a wild card for the waste category.
3. *** is a wild card for spill area (usually the size of the diked area). This can vary with the waste category and its tank size.
4. **** is a wild card for release duration. This can vary with the waste category because of the different tank sizes for different categories.
5. Each of the accident scenario codes in the last column represents several of the accident scenarios in the first column. OS-9, OS-15A, OS-21A, and OS-43E are represented by each of the first three accident scenario codes in the last column and OS-3, OS-14B, OS-15B, OS-21B, OS-53, and OS-187 are represented by each of the second accident scenario codes in the last column.

FIGURE 2-4. PROCESS OF GROUPING ACCIDENT SCENARIOS FOR CONSEQUENCE ANALYSIS

not as readily available, but there are techniques such as task analysis that can be used to provide good estimates of the likelihood of errors in performing particular operations and responding to particular emergencies. Appendix G presents the values and sources of the data used in the likelihood evaluations.

2.3.1 Likelihood Analysis Methodology

In the OWMC Hazard Analysis, the likelihood of each accident scenario code that was determined to have a potential for offsite consequences was estimated by first estimating the likelihood of each of the individual accident scenarios which generated that accident scenario code. A Boolean expression relating the component failure and/or human error events, and the frequency at which those components are used or the human actions are performed, was developed for each accident scenario. These Boolean expressions were then evaluated, using documented or calculated component failure and human error data, to determine the frequency of the accident scenarios. The frequencies for each of the accident scenarios that generate a specific accident scenario code were then combined to form the frequency of occurrence of that accident scenario code.

This method is equivalent to the use of fault trees and event trees in that fault trees and event trees can be reduced to Boolean expressions for solution. For this analysis Boolean expressions could be developed directly from the accident scenario descriptions because of the relative simplicity of the scenarios.

2.3.2 Likelihood Analysis Procedure

The likelihood analysis procedure is described in the following example. Figure 2-5 is the data file for the likelihood analysis of Accident Scenario Code "M-T-AC-45-CY-H-I" {line 1}. Two accident scenarios were identified in the Inorganic Receiving (IR) Area {line 2} that generated this accident scenario code. These scenarios are IR-143 and IR-144 {line 3} with "IR" referring to the particular facility area, Inorganic Receiving,

```
 1.  SCENARIO CODE: M-T-AC-45-CY-H-I
 2.  PLANT AREA: IR
 3.  GENERATING SCENARIOS: IR-143.,IR-144.

 4.  SCENARIOS XREF TO IR-143.: NONE
 5.  SCENARIOS XREF TO IR-144.: IR-122,IR-124,IR-125,IR-126,IR-127
 6.  SCENARIOS XREF TO IR-122: NONE
 7.  SCENARIOS XREF TO IR-124: NONE
 8.  SCENARIOS XREF TO IR-125: NONE
 9.  SCENARIOS XREF TO IR-126: NONE
10.  SCENARIOS XREF TO IR-127: NONE

11.  DESCR: "IR-143.": TRUCK GOES TO WRONG UNLOAD STATION - DRIVER ERROR
12.  DESCR: "IR-144.": TRUCK GOES TO WRONG UNLOAD STATION - OP ERROR
13.  DESCR: "IR-122":  NO SAMPLE TAKEN FROM TRUCK
14.  DESCR: "IR-124":  NONREPRESENTATIVE SAMPLE TAKEN FROM TRUCK
15.  DESCR: "IR-125":  SHIPMENT ID INCORRECT
16.  DESCR: "IR-126":  WASTE SAMPLES FROM TRUCK OR IDENTIFICATION MIXED UP
17.  DESCR: "IR-127":  LAB ERROR OF SAMPLE

18.  COMMENT:
19.  COMMENT: POSSIBILITIES:
20.  COMMENT: 1) AC TRUCK UNLOADED AT CY UNLOADING TANK
21.  COMMENT: 2) CY TRUCK UNLOADED AT AC UNLOADING TANK (INCL. IN
     CY-45-AC)
22.  COMMENT:

23.  CODE FREQ: ["'AC' TRUCK PUMPED OUT ON 'NA' SIDE FREQ" *
                 "GIVEN 'NA' UNLOAD TANK CONTAINS 'CY' PROB"]

24.  FREQ: "'AC' TRUCK PUMPED OUT ON 'NA' SIDE FREQ":
                     ["'AC' TRUCK PUMPED OUT ON 'NA' SIDE PROB" *
                      "'AC' TRUCK PUMPED OUT FREQ"]

25.  FREQ: "'AC' TRUCK PUMPED OUT ON 'NA' SIDE PROB":
                     ["IR-143." + "IR-144."]

26.  FREQ: "IR-143.": ["DRIVER TAKES TRUCK TO WRONG UNLOAD
                        STATION-H.E.PROB"]

27.  FREQ: "IR-144.": ["OPERATOR SENDS TRUCK TO WRONG UNLOAD
                        STATION-H.E.PROB" + "IR-122" + "IR-124" + "IR-125"
     + "IR-126" + "IR-127"]

28.  FREQ: "IR-122": ["NO SAMPLE TAKEN FROM TRUCK-H.E.PROB"]
29.  FREQ: "IR-124": ["NONREPRESENTATIVE SAMPLE TAKEN FROM TRUCK-H.E.PROB"]
30.  FREQ: "IR-125": ["SHIPMENT ID NUMBER INCORRECT-H.E.PROB"]
31.  FREQ: "IR-126": ["SAMPLE OR SAMPLE ID NUMBER MIXED UP-H.E.PROB"]
32.  FREQ: "IR-127": ["SAMPLE ERROR BY LAB-H.E.PROB"]
```

FIGURE 2-5. DATA FILE FOR LIKELIHOOD ESTIMATION FOR ACCIDENT SCENARIO CODE M-T-AC-45-CY-H-I

and the "143" and "144" used to identify the 143rd and 144th accident scenario identified for that area.

Next, any scenarios that were cross-referenced to the generating scenarios, or to scenarios already identified in the cross-referencing, were identified {lines 4 through 10}. In this example only Accident Scenario IR-144 {line 5} was cross-referenced by other scenarios. The cross-referenced scenarios were scenarios that would not cause an accident or upset by themselves, but do contribute to the probability that Scenario IR-144 would occur. In general, scenarios are cross-referenced because they affect the frequency of the scenario they are cross-referenced to, or have consequences identical to the scenario they are cross-referenced to, and, therefore, their frequency contributes to the likelihood of the accident scenario code being analyzed.

The next block of data {lines 11 through 17} provides a short description of each of the generating and cross-referenced scenarios. Following that is a set of comments on the scenario code {lines 18 through 22}. Note that comment 2 indicates that this inadvertent mixing of incompatible chemicals could occur in two ways, but only one way is considered here -- the other way is considered in the analysis of the Accident Scenario Code M-T-CY-45-AC-H-I where the wastes are reversed in order.

The Boolean expression for the accident scenario code is the next block of input {line 23}. This Boolean expression states that if an acidic waste truck is pumped out on the neutral/alkaline side of the inorganic unloading area AND the unloading tank that is pumped into contains a cyanide waste, an accident as described by the accident scenario code will occur. The frequency of an acidic waste truck being pumped out on the neutral/alkaline side of inorganic unloading area {line 24} is defined as the probability of an acidic waste truck being pumped out on the neutral/alkaline side multiplied by the frequency that an acidic waste truck is pumped out.

The probability that an acidic waste truck is pumped out on the neutral/alkaline side {line 25} is defined as the probability that Scenario IR-143 OR Scenario IR-144 occurs. The probability of Scenario IR-143 {line 26} is the probability of a driver error in taking the truck to the wrong unload station. The probability of Scenario IR-144 {line 27} is the probability of an operator error in sending the truck to the wrong unload station when he is given the correct unload station, plus the sum of the probabilities of the following errors (accident scenarios) that might prevent the operator from sending the truck to the correct unload station:

- No sample is taken from the truck (Accident Scenario IR-122), {line 28},
- Nonrepresentative sample is taken from the truck (Accident Scenario IR-124), {line 29},
- The truck shipment ID number is incorrect (Accident Scenario IR-125), {line 30},
- The waste sample taken from the truck was mixed up with the sample taken from another truck (Accident Scenario IR-126), {line 31}, or
- The lab made an error in analyzing the sample (Accident Scenario IR-127), {line 32}.

The data file shown in Figure 2-5 is used as input to a computer program which calculates the accident scenario code frequency. Figure 2-6 shows the output of this program for the data in Figure 2-5. In addition to the frequency of Accident Scenario Code M-T-AC-45-CY-H-I, this program output provides

- A list of basic events (events for which data values are provided),
- A list of intermediate events (events combining several basic events using a Boolean expression), and
- The frequency or probability of each of the above events which can be used for verification of the calculations.

The development of the Boolean expressions was performed in two stages. The first stage was the development of the Boolean expressions for the causes of the scenarios. The second stage was the inclusion of credit for protective measures in the Boolean expressions. This second stage was performed only for those accident scenario codes/scenarios that had a significant effect on plant risk.

```
      SCENARIO                PLANT                    FREQUENCY
        CODE                  AREA                     (PER YEAR)
__________________________    _____                    __________

M-T-AC-45-CY-H-I               IR                      7.46E-01


INTERMEDIATE EVENT NAME                                FREQUENCY OR
                                                       PROBABILITY
__________________________________________________     ___________

'AC' TRUCK PUMPED OUT ON 'NA' SIDE FREQ                5.33E+01
'AC' TRUCK PUMPED OUT ON 'NA' SIDE PROB                4.07E-02
IR-143.                                                1.00E-04
IR-144.                                                4.06E-02
IR-122                                                 3.00E-04
IR-124                                                 1.00E-04
IR-125                                                 2.00E-02
IR-126                                                 2.00E-02
IR-127                                                 1.00E-04

BASIC EVENT NAME                                       FREQUENCY OR
                                                       PROBABILITY
__________________________________________________     ___________

GIVEN 'NA' UNLOAD TANK CONTAINS 'CY' PROB              1.40E-02
'AC' TRUCK PUMPED OUT FREQ                             1.31E+03
DRIVER TAKES TRUCK TO WRONG UNLOAD STATION-H.E.PROB    1.00E-04
OPERATOR SENDS TRUCK TO WRONG UNLOAD STATION-H.E.PROB  1.00E-04
NO SAMPLE TAKEN FROM TRUCK-H.E.PROB                    3.00E-04
NONREPRESENTATIVE SAMPLE TAKEN FROM TRUCK-H.E.PROB     1.00E-04
SHIPMENT ID NUMBER INCORRECT-H.E.PROB                  2.00E-02
SAMPLE OR SAMPLE ID NUMBER MIXED UP-H.E.PROB           2.00E-02
SAMPLE ERROR BY LAB-H.E.PROB                           1.00E-04
```

FIGURE 2-6. OUTPUT FILE FOR LIKELIHOOD ESTIMATION FOR ACCIDENT SCENARIO CODE M-T-AC-45-CY-H-I

2.4 External Events Analysis

Seismic events (earthquakes) and tornadoes are external (natural) events that have the potential for damaging a facility such as the OWMC Treatment Facility and cause a release of a hazardous material. Thus, the OWMC Hazard Analysis should include the potential contribution of seismic events and tornadoes to the total facility risk.

Both the event frequency and the potential accident consequence must be considered. However, compared to the frequencies and consequences of single equipment failures and human errors:

- Seismic events and tornadoes are considerably more rare than single equipment failures or human errors.
- The consequences of multiple equipment failures resulting from seismic events and tornadoes are potentially much greater than the consequences of plant upsets from single equipment failures or human errors.
- It is more difficult to estimate the frequency or consequences of the natural events by mathematical phenomenological models of the events themselves than it is to estimate the frequency of single equipment failures or human errors.

Therefore, the approach usually taken to analyze the risk of external events is to use historical data for both the frequency of the events and for the damage from the events as a function of event magnitude as input to a bounding analysis. The bounding analysis estimates the frequency of events with magnitudes sufficient to cause multiple equipment failures. The most conservative values for frequency of event and fragility of equipment that can be found in the literature are used in the bounding analysis. Hence, the results are expected to bound the "actual answer" on the conservative side.

2.4.1 Seismic Events

This assessment estimates the bounding frequency of multiple onsite failures of the waste storage equipment planned for the OWMC Facility due to seismic events. This estimate is based on estimates of seismic event frequencies at the site, and data from other seismic analyses on the fragility of tanks as a function of seismic event magnitude.

2.4.1.1 Estimation of Seismic Frequency. The estimate needed is the frequency vs. magnitude of seismic events which have the potential for equipment damage. This magnitude must be expressed as peak ground acceleration to relate to equipment failures. For the OWMC Facility in the St. Catharines area, a bounding seismic frequency vs. magnitude was developed from several references, including a seismic risk assessment (NUS, 1983) for the Limerick Nuclear Power Plant in Pennsylvania. Figure 2-7 shows the bound as a solid line between the two "X"s and dotted lines outside each "X". Each "X" was taken from data (Petak and Atkisson, 1982) for the St. Catharines area. Specifically, the left "X" represents an earthquake with a horizontal acceleration of 0.09 g with a 90 percent probability of not being exceeded in 50 years, and the right "X", taken from the same reference, represents the 475-year return period for an earthquake with a Modified Mercalli Intensity (MMI) measure of VII to VIII.

The MMI scale is based on damage reports and does not directly provide the ground acceleration. However, the Limerick Risk Assessment presents a conservative relationship between acceleration and the MMI scale such that a VII is equated to 0.3 g and the VIII to 0.5 g. The high acceleration portion of the dotted line is formed by utilizing the Limerick upperbound slope for the same portion on their seismic frequency graph; this portion is an extrapolation beyond the recorded seismic history of the area, but necessary to consider in the assessment of risk for large seismic events. The low acceleration dotted line is simply the extrapolation for lower magnitude events. To help confirm that this bounding estimate is reasonable, the straight lines are compared to the recorded seismic events (from the Limerick Risk Assessment) within 100 km of St. Catherines recorded over the past 300 years. This is shown by the MMI scale, aligned with the acceleration scale, and plotted as the four circles on Figure 2-7. These points are also conservative because the conservative acceleration vs. MMI was used, and no attenuation due to the distance of the recorded events from the site was assumed. As can be seen, these points agree reasonably well with the straight-line bound.

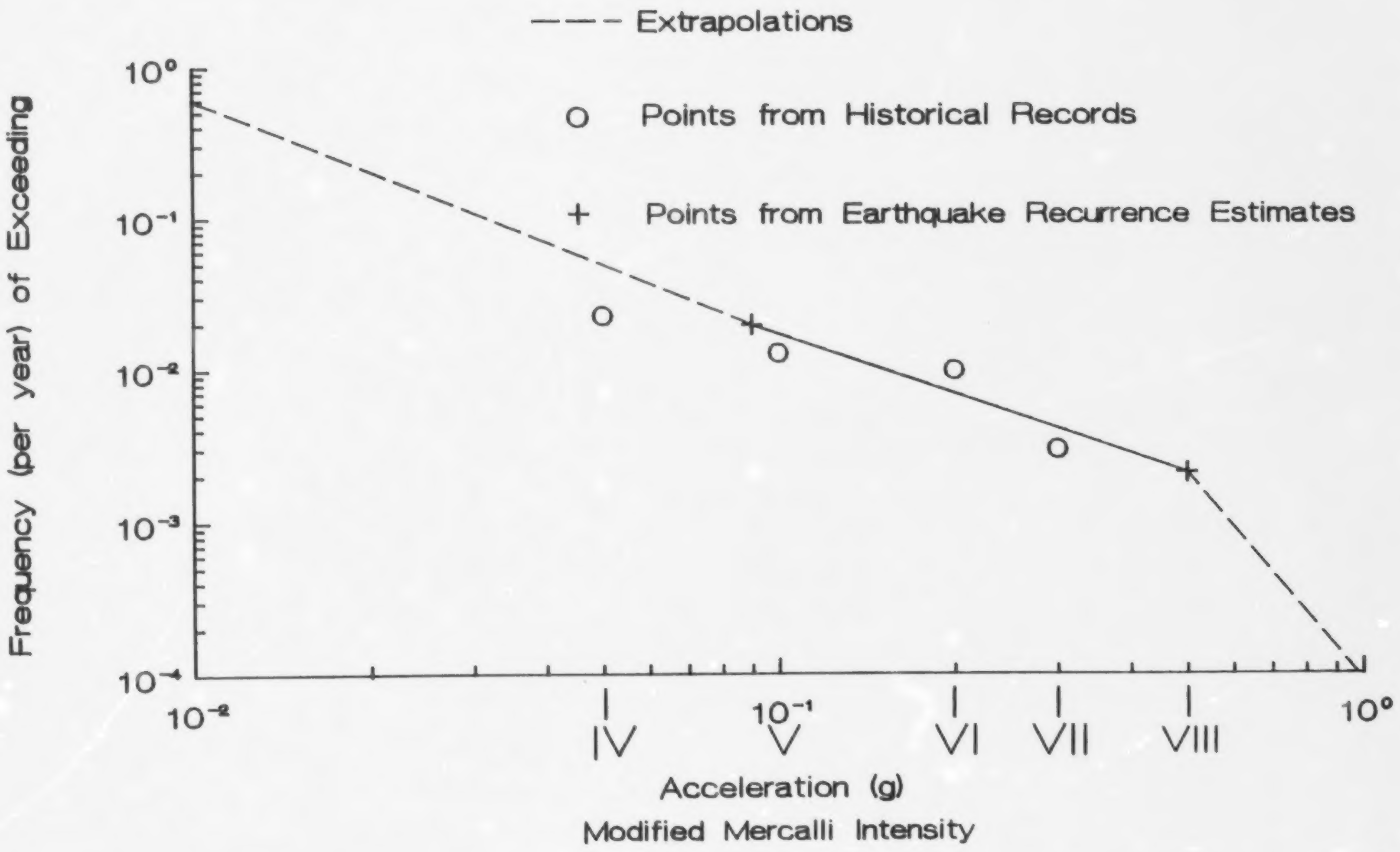


FIGURE 2-7. BOUNDING EARTHQUAKE ESTIMATES FOR ST. CATHARINES (HART, 1976)

The graph in Figure 2-7 is a complementary cumulative distribution function, and, for the subsequent risk estimations, it is convenient to form the density function from this in a discretized form. This process is aided by fitting a function to the distribution. Thus, the graph for the frequency of exceeding seismic magnitudes can be expressed as

$$\text{for } 0.01 < g < 0.5 : \quad f = (4.87 \times 10^{-4})\, g^{-1.545}$$

$$\text{for } 0.5 < g < 1.0 : \quad f = (1.00 \times 10^{-4})\, g^{-3.829}$$

2.4.1.2 Vessel Fragility. The Electric Power Research Institute (EPRI, 1985) has published a report which provides component fragility for several nuclear power plants. Those of interest here are tanks which can fail at accelerations less that 1.0 g. This fragility is reported for two points on a log-normal probability distribution; namely, the acceleration where the equipment fails with a 50 percent probability and the acceleration where there is a 10 percent chance of failure. The relevant equipment failure points are given for the most fragile equipment items found in the plants, to one significant figure

Equipment	Probability of Failure	
	50%	10%
Refueling water storage tank	0.7g	0.3g
Condensate storage tank	0.2g	0.1g
City water storage tank	0.3g	0.1g

Since these fragilities are expressed as a log-normal probability distribution, the fragility is available for any magnitude of seismic event.

For the bounding analysis of the OWMC Facility, it is assumed that all tanks and vessels have a fragility equal to the most fragile tank in the EPRI report -- the condensate storage tank. Further, since only multiple failures of tanks containing organic waste types would have a consequence greater than the consequences based on HAZOPS scenarios, the probability of two, three, and four or more tanks failing was estimated. This was done for tank groups of two, three, and six. These groups correspond to the liquid blending, halogenated, and waste solvent tanks.

These groups were selected because they would be expected to have the worst offsite consequences if their contents were spilled.

2.4.1.3 Bounding Risk Estimate. The results from the equipment fragility bounds and the seismic frequency were combined to estimate the frequency of tank failures in the critical storage areas due to seismic events. The results are

Tank Type (No. of Tanks)	Frequency of Failures per 1,000 yr		
	>1	>2	>3
Liquid blending (2)	12	4.5	N/A
Halogenated (3)	15	6.8	3.3
Waste Solvent (6)	20	11	7.5

If the seismic effects on these three tank areas are combined, it can be estimated that more than one tank will fail in one or more of these areas at a frequency of 4.7×10^{-2} per year.

2.4.2 Tornado Events

As with seismic events, the damage caused by tornadoes of different intensities and the frequency of occurrence of tornadoes with those intensities are the variables of interest for estimating the potential contribution to facility risk from tornadoes. Both the occurrence and the consequences of tornadoes are difficult to model and it is necessary to base estimations of risk on the available historical data on damage and frequency. The number of tornados reported in any geographical region varies from year to year based on changing meteorological conditions and population densities. Areas of less population tend to have more unreported tornadoes than do densely populated areas. Nevertheless, there is a considerable body of data that can be used to predict the risk from these external events.

2.4.2.1 Estimation of Tornado Damage. The damage caused by tornadoes has been related to their intensity by the Fujita Scale. This is the standard method of relating tornado intensity, as expressed by the maximum tornado wind speed, to observed damage (LLNL, 1985)(McDonald, 1983). The classifications on the Fujita Scale range from a minimum of F0 to a maximum of F6. Table 2-7, Fujita's F-Scale Classification of Tornadoes Based on Damage, gives a verbal description of typical damage and the range of wind speeds for each tornado classification. Figure 2-8 relates the percent damage to both metal structures and concrete structures to wind speed for "Typical Industrial Structures" (Hart, 1976).

Examination of Figure 2-8 suggests that measureable damage normally occurs when wind speeds reach about 200 km/h and becomes significant when speeds of 300 km/h are present. This correlates well with the descriptions of damage in Table 2-7 for intensities of F2 and greater on the Fujita Scale. This leads to a conservative estimate that tornadoes of intensity F2 or greater striking any part of the Incinerator Tank Farm will result in multiple tank failures.

2.4.2.2 Estimation of Tornado Frequency. The probability that a tornado will strike a point or small area within a region can be estimated using a geometric approach such as

$$P(s) = A(t) / (A(r) \times N(y))$$

where:

$P(s)$	is the strike probability,
$A(t)$	is the total area affected by all the tornadoes reported in a region in a certain period,
$A(r)$	is the area of the region, and
$N(y)$	is the number of years in the recording period for which the tornado area was calculated (PNL, 1986)

In order for this estimation to be accurate, the point or small area for which the strike probability is being calculated must be small compared to the area of the region. In addition, the tornadoes must be assumed to occur randomly over the region of interest.

The data and method of calculation used in this section of this report come from both NUREG/CR-4461 (PNL, 1986) and the National Severe

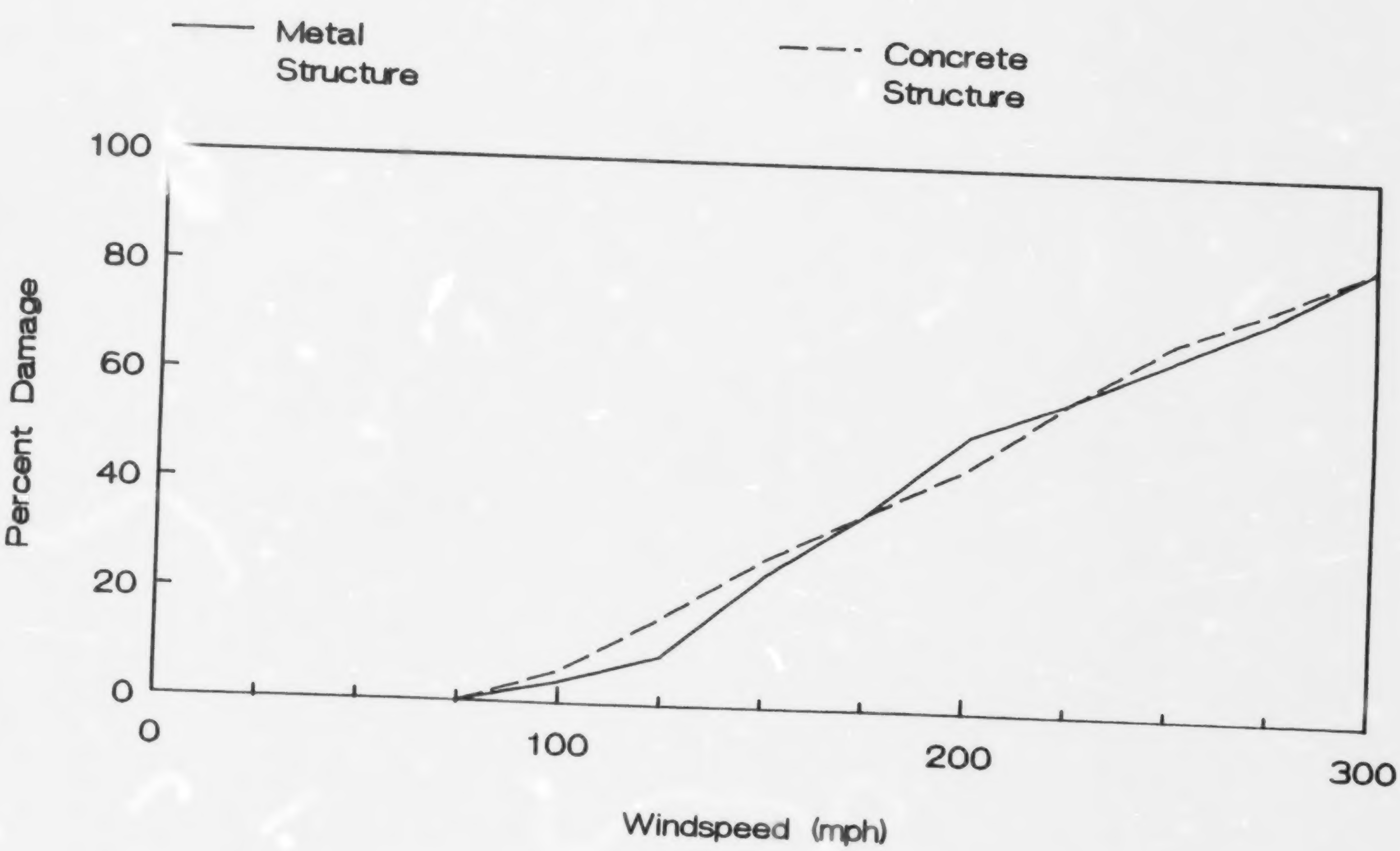


FIGURE 2-8. WIND DAMAGE DATA-TYPICAL INDUSTRIAL STRUCTURES

Storms Forecast Center (NSSFC) database on tornado climatology in Kansas City, Missouri. The area of interest is the St. Catharines region which is included in the 5° box whose southeast corner is at 40°N 75°W and the 1° box whose southeast corner is at 42°N 79°W.

Over the 30 year period ($N(y)=30$) from 1954 to 1983, there were a total of 12 tornadoes reported which occurred in the 1° box specified earlier and the average area covered by these tornadoes was 3.1 km^2 (1.2 mi^2). From this, the total area affected by the tornadoes ($A(t)$) can be calculated as follows:

$$A(t) = 3.1\ km^2 \times 12$$

$$A(t) = 37.3\ km^2$$

The area of the region ($A(r)$) is calculated to be

$$A(r) = 12{,}420\ km^2 \times \cos(42.5)$$

$$A(r) = 9157\ km^2$$

where 42.5 is the latitude of the middle of the 1° box and 12,420 km^2 is the area of a 1° box at the equator. From these numbers, the strike probability for the area can be calculated to be

$$P(s) = 1.36 \times 10^{-4}/yr.$$

However, a correction factor needs to be applied to this number since the NSSFC database includes only those tornadoes which occurred in the United States portion of the area. The correction factor is the ratio of the box area to the U.S. land area in the box. For the 1° box in question the correction factor is approximately 2. This gives a corrected strike probability ($P(sc)$), for tornadoes of any intensity, of

$$P(sc) = 2.71 \times 10^{-4}/yr.$$

It is now necessary to estimate the frequency of tornadoes of intensity level F2 and above, since this intensity level is necessary for significant damage to occur. It can be assumed that the tornado dimensions (length, width, intensity) fall into a log-normal distribution. This assumption is not a universally accepted one. Howe (Howe, 1974) and Twisdale (Twisdale, 1978) have challenged this assumption, but the calculations in the NSSFC database do assume this distribution. With this

TABLE 2-7. FUJITA'S 1971 F-SCALE CLASSIFICATION OF TORNADOES BASED ON DAMAGE

Scale	Damage	Wind Speed (kmph)	Description of Tornado
F0	Light	B104-187	Corresponds to Beaufort 9 through 11. Some damage to chimneys, TV antennae, signboards; tree branches broken; shallow-rooted trees pushed over; old, hollow trees break or fall.
F1	Moderate	188-291	The beginning of hurricane wind speed or Beaufort 12 is 188 kmph. Surfaces peeled off roofs; windows broken; trailer houses moved or overturned; trees on soft ground uprooted; some trees snapped; moving autos pushed off roads.
F2	Considerable	292-408	Roofs torn off frame houses, leaving strong upright walls; weak-structured outbuildings and trailer houses demolished; railroad boxcars pushed over; large trees snapped or uprooted; light-object missiles generated; cars blown off highways; block structures damaged badly.
F3	Severe	409-536	Roofs and some walls torn off well-constructed frame houses; some rural buildings demolished completely; trains overturned; steel-framed warehouse structures torn; cars lifted off ground and rolled some distance; most trees in a forest uprooted, snapped, or leveled; block structures often leveled.
F4	Devastating	537-676	Well-constructed frame houses leveled, leaving debris; structures with weak foundations lifted, torn, and blown some distance; trees debarked by small flying objects; sandy soil eroded and gravel flies; cars thrown or rolled some distance, finally disintegrating; large missiles generated.
F5	Incredible	677-827	Strong frame houses lifted off foundations and carried considerable distances to disintegrate; steel-reinforced concrete badly damaged; auto-sized missiles fly distances of 100 yds or more; trees debarked completely; incredible phenomena can occur.
F6	Inconceivable	828-sonic	The extent and types of damage may not be conceived. Missiles such as iceboxes, water heaters, storage tanks, and automobiles fly long distances, creating serious secondary damage on structures. Assessment of damage is feasible only through detailed surveys involving engineering and aerodynamical calculations, as well as meteorological models of tornadoes.

assumption, and the appropriate detailed information (dimensions, intensity) on the individual tornado occurrences, class strike probabilities could be calculated for each intensity level on the Fujita Scale. In addition, the strike exceedance probability for each intensity level could be calculated. The strike exceedance probability is the probability of a strike of equal or greater intensity than a particular level.

Unfortunately, the detailed information for the individual tornado occurrences was not available to calculate the class strike probabilities and the strike exceedance probabilities for the 1° box. However, Appendix D of NUREG/CR-4461 (PNL, 1986) has this information for 5° boxes covering the contiguous United States and portions of Canada and Mexico and, for the 5° box of interest, provides the class strike probabilities and the strike exceedance probabilities directly, as shown in Table 2-8.

TABLE 2-8. STRIKE PROBABILITIES

	Tornado Intensity (F-Scale) (E-05 per year)					
	0	1	2	3	4	5
Expected class strike prob.	0.075	1.0	2.36	1.6	–	–
Expected strike exceedance prob.	6.08	5.91	4.85	1.8	–	–

In examining the class strike and strike exceedance probabilities in Table 2-8, it can be seen that the probability of exceedance for intensity level F2 is approximately equal to (80 percent of) the probability of exceedance for intensity level F0 (the probability that a tornado of any intensity will occur). This implies that when tornadoes do form, at least in this 5° box, they tend to form with significant strength.

Now, if it is assumed that the distribution of intensities for the 1° box is the same as for the 5° box for the St Catharines region, the strike exceedance probability for an intensity level F2 tornado for the 1° box can be said to be approximately equal to the strike probability of a tornado of any intensity for that box. The latter was calculated earlier, from data for the 1° box to be

$$P(s) = 2.71 \times 10^{-4}/\text{yr}.$$

2.4.2.3 Bounding Risk Estimate. Since the probability that there will be a significant release if an F2 class tornado strikes the Incinerator Tank Farm is essentially unity, the probability of a significant release happening in any year is essentially equal to the strike exceedance probability for a tornado of intensity F2. This has been shown earlier to be essentially equal to the strike probability for the site. Thus, for the 1° box whose southeast corner is at 42°N 79°W, the strike probability for a tornado that could cause significant damage and release of material is

$$P(s) = 2.71 \times 10^{-4}/\text{yr}$$

3.0 SUMMARY OF RESULTS OF HAZARD ANALYSIS

Summarized in this chapter are the results of the hazard analysis. This effort took the hazards identified during the Hazrds and Operability Study (HAZOPS) sessions and systematically evaluated the potential risk of handling typical wastes in the proposed facility.

3.1 Potential Accidents Identified

3.1.1 Number and Type of Accident Scenarios Identified

Over 10,000 potential accidents were identified in the course of the hazard analysis. These included mostly liquid spill and inadvertent mixing scenarios and their possible hazardous consequences, but also included bursting vessel explosions and other process hazards such as asphyxiation and chemical burns. The consequences of each accident event sequence (accident scenario) were evaluated using the methods described in Appendix D.

3.1.2 Number and Type Requiring Quantitative Analysis

Several hundred accident scenario codes were identified as potentially having some undesirable effects, including odor, irritation, reversible health effects, and/or irreversible health effects. Nearly 100 of these scenarios were assessed as having significant potential offsite effects in terms of reversible/irreversible/lethal health effects. Several scenarios involving the mixing of incompatible chemicals showed large potential consequences; as a result of the initial analysis, the mixing operations as a whole were reevaluated. None of the accident scenario codes were eliminated on the basis of frequency of occurrence alone.

After detailed analysis of the important accident scenarios, 77 of the accident scenario codes still showed significant potential offsite effects (reversible or greater health effects outside the boundary of the proposed site location). The likelihood of occurrence for each of these remaining codes was evaluated based on the accident scenarios which the codes represented, including the probability of ignition for scenarios involving fires. The likely number of people affected by each scenario was also assessed, using the method described in the next section. These likelihood and consequence measures were then combined to calculate the facility risk estimates, which are summarized in Section 4.

3.2 Quantitative Analysis of Individual Accident Scenarios

The accident scenarios having offsite reversible/irreversible health effect consequences were all associated with the release of toxic vapors. The release mechanism for these scenarios was either an all-vapor release from the process, generation of toxic vapors from the mixing of incompatible materials, toxic combustion products from a pool fire, or entrainment of unburned material (notably PCBs) with the combustion products in a pool fire.

The consequences of the vapor release events were evaluated in two basic steps. First, dispersion of the toxic vapors was modeled by ORTECH International, an organization consulting to the Ontario Waste Management Corporation (OWMC). This modeling included consideration of release elevation and building wake effects. The dispersion results were given as maximum plume centerline distances to reversible, irreversible, and lethal health effect levels (as detailed in Appendix D-8) under unfavorable meteorological conditions (2 m/s wind speed; slightly stable atmosphere). Second, these maximum distances were used to overlay a plume with the calculated length and a 10:1 length-to-width ratio (approximating the plume profile under the meteorological conditions given above) on a plot of the surrounding area, as illustrated in Figure 3-1 for a 1,800-m plume. This overlaying was done mathematically using computer calculations, such that the effect on all residences within the radius of the maximum plume length was precisely evaluated for each scenario.

The likely number of people within the plume path was evaluated as the average number of persons affected, weighted by actual wind directional data for the proposed site location. No credit was given for persons taking self-protection measures such as going indoors until the plume of vapors goes by.

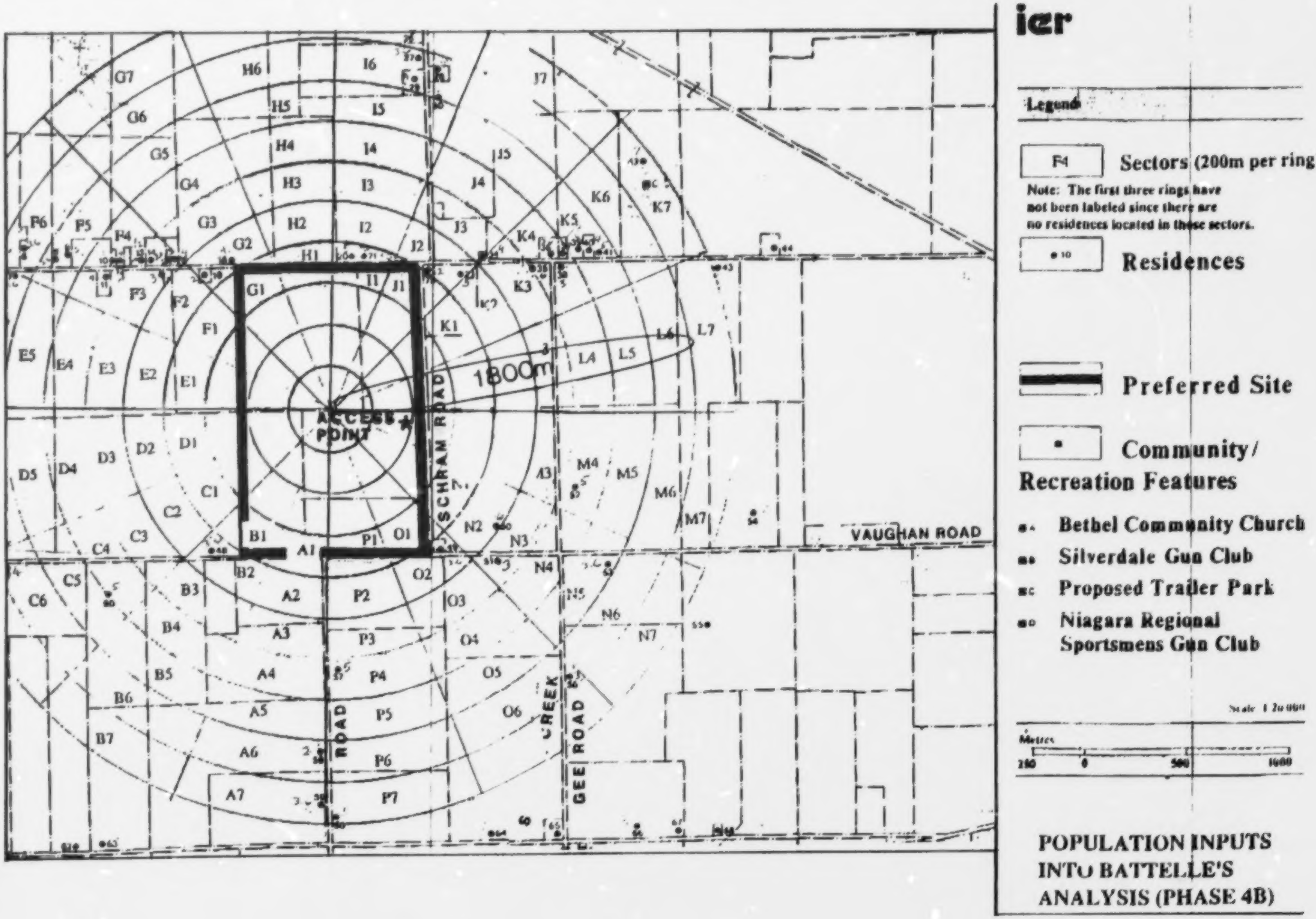

icr
Legend
F4 Sectors (200m per ring)
Note: The first three rings have not been labeled since there are no residences located in these sectors.
• 10 Residences
Preferred Site
Community/ Recreation Features
A Bethel Community Church
B Silverdale Gun Club
C Proposed Trailer Park
D Niagara Regional Sportsmens Gun Club
Scale 1:20 000
Metres
200 0 500 1000
POPULATION INPUTS INTO BATTELLE'S ANALYSIS (PHASE 4B)
ACCESS POINT
1800m
SCHRAM ROAD
VAUGHAN ROAD
GEE ROAD
CREEK
ROAD

FIGURE 3-1. ILLUSTRATION OF CONSEQUENCE ANALYSIS FOR 1800-m PLUME

Population data used in this analysis were provided by IER, another organization consulting to OWMC. These data were generated by a field survey of all residences within 8 km of the proposed site, and included the actual number of persons per household for residences within 2 km of the site. Residences beyond 2 km were assumed to have an average number of persons per household of 3.4, based on 1986 census data for the township.

For the few scenarios which had effects extending beyond 8 km, the population data as a function of distance from zero to 8 km was extrapolated. The average number of people affected is a fairly smooth function of the maximum plume length, as seen in Figure 3-2. Thus, the extrapolation from 8 km to a maximum of 15 km is not expected to introduce a significant error in the consequence analysis results.

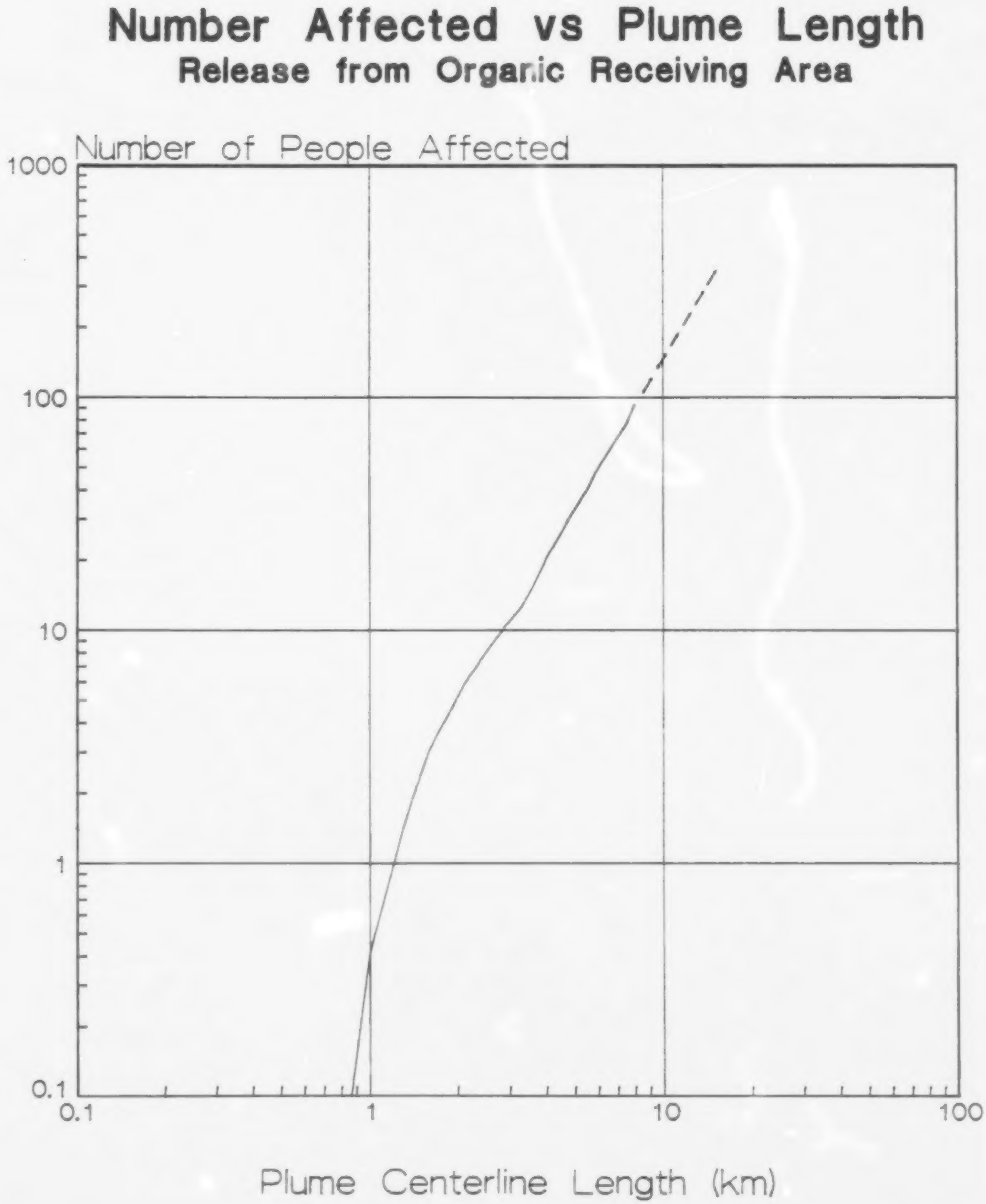


FIGURE 3-2. NUMBER OF PEOPLE AFFECTED VS. PLUME LENGTH (ORGANIC RECEIVING)

4.0 ASSESSMENT OF FACILITY RISK

The quantitative results of the hazard analysis, giving the total facility risk with respect to the handling of typical wastes, are presented in this section. The results presented are for offsite (public) risk measures only.

Two measures of risk were estimated. The societal risk measure expresses the risk to society as a whole. The individual risk measure specifies the maximum level of risk to which any individual may be exposed. Individual risk is estimated for the "maximum exposed individual". This hypothetical person is presumed to be an average, healthy adult living on the edge of the facility buffer zone (400 m from the perimeter of the core zone which is within the Central Operations Area of the facility) 24 hours per day, 365 days per year, for the lifetime of the facility, and located at the spot along the buffer zone where the maximum likelihood of exposure for each potential accident scenario occurs.

A summary of quantitative results for offsite risks is given in Table 4-1 below. These same results are given in greater detail in Tables 4-2 (societal risk measures) and 4-3 (individual risk measures), and are discussed in this section according to the severity of the effects (reversible, irreversible, and lethal health effects).

TABLE 4-1. QUANTITATIVE SUMMARY OF FACILITY RISK

Health Effect Level	Offsite Societal Risk(1)	Offsite Individual Risk(2)
Reversible	0.45/yr (1 per 2 yr)	0.008/yr (1 per 130 yr)
Irreversible	0.013/yr (1 per 80 yr)	0.0017/yr (1 per 600 yr)
Lethal	7×10^{-5}/yr (1 per 14,000 yr)	7×10^{-5}/yr (1 per 14,000 yr)

(1) Point risk estimate of the total facility risk, including consideration of likely number of health effects per scenario.

(2) Risk to hypothetical individual at fenceline of proposed site, at worst location for each scenario.

TABLE 4-2. SOCIETAL RISK SUMMARY FOR OFFSITE POPULATIONS

Area	Accident Scenario Code	Mech-anism	Release Rate (g/s)	Release Dur. (min)	Release Chem-ical	Effect Radius (m) Revers.	Effect Radius (m) Irrev.	Effect Radius (m) Lethal	Number Affected Revers.	Number Affected Irrev.	Number Affected Lethal	Total Frequency (/yr)	Health Effects (per year) Revers.	Health Effects (per year) Irrev.	Health Effects (per year) Lethal
Organic Drum Storage and Handling Building — toxic combustion product and entrainment scenarios															
OD	L-HW-A-10-0-A	TCP	200	1.9	HCl	700	250	—	0.02	0.00	0.00	9.1E-06	1.81E-07	0	0
OD	L-HW-B-20-0-A	TCP	400	1.9	HCl	900	500	150	0.15	0.00	0.00	2.2E-03	3.22E-04	0	0
OD	L-HW-C-50-3-A	TCP	56	30	HCl	600	—	—	0.00	0.00	0.00	6.2E-03	0	0	0
OD	L-HW-D-100-1-A	TCP	670	5	HCl	1800	700	—	3.63	0.02	0.00	6.5E-06	2.36E-05	1.30E-07	0
OD	L-HW-D-80-0-A	TCP	1600	2.4	HCl	1800	1000	375	3.63	0.24	0.00	1.3E-06	4.68E-06	3.10E-07	0
OD	L-HW-E-160-0-A	TCP	3200	2.4	HCl	2400	1400	700	7.07	1.42	0.02	1.0E-08	7.07E-08	1.42E-08	2.00E-10
OD	L-HW-G-1000-2-A	TCP	3300	10	HCl	5000	2600	900	33	8.34	0.15	6.5E-06	2.14E-04	5.43E-05	9.77E-07
OD	L-HW-G-1000-3-A	TCP	1100	30	HCl	4500	900	200	26	0.15	0.00	3.7E-03	9.75E-02	5.59E-04	0
OD	0-OR-44(HW)	TCP	3800	2	HCl	2400	1400	700	7.07	1.42	0.02	1.7E-06	1.22E-05	2.44E-06	3.44E-08
OD	0-OR-44(SW)	TCP	6.4	2.8	COCl2	1000	700	—	0.24	0.02	0.00	1.0E-08	2.40E-09	2.00E-10	0
OD	0-OR-44(SW)	NTR	94	2.8	PCBs	1800	1400	—	3.63	1.42	0.00	1.0E-08	3.63E-08	1.42E-08	0
OD	0-OR-46(HW)	TCP	5100	15	HCl	9000	1800	600	120	3.63	0.00	1.7E-07	2.06E-05	6.24E-07	0
Organic Tank Truck Unloading Area — toxic combustion product and entrainment scenarios															
OR	L-HW-B-17-0-A	TCP	350	2.2	HCl	1000	600	150	0.41	0.00	0.00	1.4E-04	5.82E-05	0	0
OR	L-HW-B-29-1-A	TCP	130	5	HCl	650	—	—	0.00	0.00	0.00	7.1E-05	0	0	0
OR	L-HW-C-17-0-A	TCP	340	5.6	HCl	900	350	—	0.15	0.00	0.00	8.1E-06	1.22E-06	0	0
OR	L-HW-C-46-3-A	TCP	56	30	HCl	600	—	—	0.00	0.00	0.00	7.5E-03	0	0	0
OR	L-HW-C-50-2-A	TCP	170	10	HCl	1400	300	—	1.89	0.00	0.00	1.6E-02	3.01E-02	0	0
OR	L-HW-D-26-2-A	TCP	330	10	HCl	900	350	—	0.15	0.00	0.00	1.0E-08	1.50E-09	0	0
OR	L-HW-D-64-1-A	TCP	670	5	HCl	1800	725	300	4.04	0.01	0.00	1.9E-06	7.60E-06	1.88E-08	0
OR	L-HW-E-29-1-A	TCP	590	13	HCl	1200	450	—	0.96	0.00	0.00	4.1E-06	3.91E-06	0	0
OR	L-HW-F-54-3-A	TCP	560	30	HCl	2600	600	—	8.62	0.00	0.00	1.0E-08	8.62E-08	0	0
OR	L-HW-F-64-1-A	TCP	1300	15	HCl	2000	800	250	5.18	0.02	0.00	1.1E-05	5.85E-05	2.26E-07	0
OR	L-HW-G-75-3-A	TCP	1100	30	HCl	4500	900	250	26	0.15	0.00	1.0E-08	2.61E-07	1.50E-09	0
OR	L-HW-G-92-0-A	TCP	1900	21	HCl	7000	1400	350	67	1.89	0.00	9.2E-04	6.16E-02	1.74E-03	0
OR	L-HW-H-107-3-A	TCP	2200	35	HCl	15000	2200	450	320	6.38	0.00	4.3E-04	1.37E-01	2.73E-03	0
OR	L-HW-H-131-3-A	TCP	2200	30	HCl	8000	1400	400	92	1.89	0.00	1.0E-08	9.23E-07	1.89E-08	0
OR	L-HW-H-152-0-A	TCP	3100	25	HCl	12500	1800	450	230	4.04	0.00	5.3E-05	1.22E-02	2.14E-04	0
OR	L-ON-F-50-0-A	TCP	220	9	HCl	700	250	—	0.00	0.00	0.00	3.2E-03	0	0	0
OR	L-ON-H-28-1-A	TCP	44	5	COCl2	1600	850	—	3.05	0.09	0.00	1.0E-02	3.04E-02	8.98E-04	0

TABLE 4-2. (Continued)

	Accident		Release			Effect Radius (m)			Number Affected			Total Frequency	Health Effects (per year)		
Area	Scenario Code	Mech-anism	Rate (g/s)	Dur. (min)	Chem-ical	Revers.	Irrev.	Lethal	Revers.	Irrev.	Lethal	(/yr)	Revers.	Irrev.	Lethal
OR	L-SW-C-17-0-A	NTR	8.9	7	PCBs	850	300	—	0.09	0.00	0.00	4.0E-08	3.60E-09	0	0
OR	L-SW-C-50-3-A	NTR	2.2	30	PCBs	450	—	—	0.00	0.00	0.00	8.7E-06	0	0	0
OR	L-SW-D-64-1-A	TCP	1.8	5	COCl2	400	300	—	0.00	0.00	0.00	4.0E-07	0	0	0
OR	L-SW-D-64-1-A	NTR	26	5	PCBs	700	500	—	0.00	0.00	0.00	4.0E-07	0	0	0
OR	L-SW-E-29-1-A	NTR	15	17	PCBs	1400	600	—	1.89	0.00	0.00	2.0E-08	3.78E-08	0	0
OR	L-SW-F-64-1-A	NTR	34	20	PCBs	4000	900	—	20	0.15	0.00	8.0E-07	1.62E-05	1.20E-07	0
OR	L-SW-H-107-3-A	TCP	6	30	COCl2	600	200	—	0.00	0.00	0.00	2.1E-06	0	0	0
OR	L-SW-H-107-3-A	NTR	87	30	PCBs	5000	1600	—	33	3.05	0.00	2.1E-06	6.92E-05	8.40E-06	0
OR	L-SW-H-152-0-A	TCP	5.4	33	COCl2	900	300	—	0.16	0.00	0.00	2.6E-05	3.90E-06	0	0
OR	L-SW-H-152-0-A	NTR	80	33	PCBs	8000	2400	—	92	7.50	0.00	2.6E-05	2.40E-03	1.95E-04	0
OR	L-SW-H-415-0-A	TCP	2.2	12	PCDFs	600	600	—	0.00	0.00	0.00	1.0E-08	0	0	0
OR	L-WS-I-152-3-A	TCP	72	46	SO2	600	150	—	0.00	0.00	0.00	1.0E-08	0	0	0
Inorganic Drum Storage and Handling Building — toxic combustion product scenarios															
ID	L-HW-B-20-0-A	TCP	400	1.9	HCl	1000	600	150	0.57	0.00	0.00	2.1E-04	1.20E-04	0	0
ID	L-HW-D-80-0-A	TCP	1600	2.4	HCl	2000	1000	600	5.46	0.57	0.00	1.3E-07	7.04E-07	7.35E-08	0
Inorganic Tank Truck Unloading Area — toxic combustion product scenarios															
IR	L-HW-H-64-0-M	TCP	1300	59	HCl	9000	1600	350	120	3.26	0.00	2.1E-04	2.52E-02	6.85E-04	0
IR	L-NA-H-12-0-A	TCP	51	1.9	NOx	700	150	125	0.00	0.00	0.00	1.4E-08	0	0	0
Inorganic Tank Truck Unloading Area — inadvertent mixing scenarios															
IR	M-T-AC-10-NaHS-H-I	MIX	470	60	H2S	2400	900	350	7.67	0.23	0.00	4.6E-04	3.51E-03	1.05E-04	0
IR	M-T-AC-10-NaHSO3-H-I	MIX	880	60	SO2	2000	800	600	5.42	0.09	0.00	4.6E-04	2.48E-03	4.12E-05	0
IR	M-T-AC-10-NaOCl-H-I	MIX	490	60	Cl2	3500	1400	700	14	2.09	0.00	4.6E-04	6.59E-03	9.57E-04	0
IR	M-T-FeCl3-10-NaHS-H-I	MIX	1200	5	H2S	2400	1400	475	7.67	2.09	0.00	8.8E-06	6.72E-05	1.83E-05	0
IR	M-T-FeCl3-10-NaHSO3-H-I	MIX	2200	5	SO2	3000	1600	475	11	3.26	0.00	1.0E-05	1.14E-04	3.36E-05	0
IR	M-T-FeCl3-10-NaOCl-H-I	MIX	820	5	Cl2	3500	1600	450	14	3.26	0.00	1.1E-05	1.54E-04	3.49E-05	0
IR	M-T-H2SO4-10-NaHS-H-I	MIX	3300	5	H2S	4000	2000	825	20	5.42	0.13	1.6E-04	3.22E-03	8.78E-04	2.11E-05
IR	M-T-H2SO4-10-NaHSO3-H-I	MIX	6200	5	SO2	5000	2200	825	33	6.56	0.13	1.6E-04	5.38E-03	1.08E-03	2.13E-05
IR	M-T-H2SO4-10-NaOCl-H-I	MIX	3400	5	Cl2	7000	2600	850	66	8.75	0.16	1.6E-04	1.09E-02	1.44E-03	2.62E-05
IR	M-T-NaHS-10-FeCl3-H-I	MIX	1000	5	H2S	2200	1200	450	6.56	1.14	0.00	4.4E-06	2.91E-05	5.05E-06	0

TABLE 4-2. (Continued)

			Release			Effect Radius (m)			Number Affected			Total	Health Effects (per year)		
Area	Accident Scenario Code	Mech-anism	Rate (g/s)	Dur. (min)	Chem-ical	Revers.	Irrev.	Lethal	Revers.	Irrev.	Lethal	Frequency (/yr)	Revers.	Irrev.	Lethal
IR	M-T-NaHS-10-H2SO4-H-I	MIX	1000	5	H2S	2200	1200	450	6.56	1.14	0.00	5.5E-06	3.60E-05	6.26E-06	0
IR	M-T-NaHSO3-10-FeCl3-H-I	MIX	850	5	SO2	2000	725	—	5.42	0.01	0.00	2.2E-04	1.21E-03	2.23E-06	0
IR	M-T-NaHSO3-10-H2SO4-H-I	MIX	850	5	SO2	2000	725	—	5.42	0.01	0.00	2.2E-04	1.22E-03	2.25E-06	0
IR	M-T-NaOCl-10-FeCl3-H-I	MIX	330	5	Cl2	2400	725	—	7.67	0.01	0.00	2.8E-04	2.11E-03	2.75E-06	0
IR	M-T-NaOCl-10-H2SO4-H-I	MIX	330	5	Cl2	2400	725	—	7.67	0.01	0.00	2.8E-04	2.12E-03	2.77E-06	0
Phys/Chem Storage Tank Area — toxic combustion product scenarios															
IS	L-NA-I-165-0-A	TCP	700	0.34	NOx	800	350	300	0.20	0.00	0.00	9.9E-03	1.98E-03	0	0
IS	L-UIN-H-150-0-A	TCP	750	0.22	SO2	450	—	—	0.00	0.00	0.00	1.6E-03	0	0	0
Phys/Chem Storage Tank Area — inadvertent mixing scenarios															
IS	M-T-NaHS-45-AC-I-I	MIX	4400	6	H2S	5000	2200	850	33	6.67	0.31	7.9E-06	2.58E-04	5.26E-05	2.45E-06
IS	M-T-NaHSO3-45-AC-I-I	MIX	2500	7	SO2	3500	1800	450	14	4.45	0.00	9.5E-06	1.37E-04	4.22E-05	0
IS	M-T-NaOCl-45-AC-I-I	MIX	1400	18	Cl2	9000	2550	800	120	8.56	0.20	9.9E-06	1.19E-03	8.46E-05	1.98E-06
Phys/Chem Treatment Building — inadvertent mixing and process deviation/vapor release scenarios															
IT	M-T-NaHS-50-AC-I-I	MIX	4900	5.5	H2S	5000	2200	600	32	6.59	0.00	3.1E-07	9.99E-06	2.03E-06	0
IT	M-T-NaHSO3-10-AC-I-I	MIX	570	30	SO2	1000	—	—	0.69	0.00	0.00	8.6E-05	5.93E-05	0	0
IT	M-T-NaHSO3-50-AC-I-I	MIX	2800	6	SO2	3500	1600	—	14	3.40	0.00	4.7E-07	6.68E-06	1.59E-06	0
IT	M-T-NaOCl-15-AC-I-I	MIX	470	33	Cl2	3000	1200	400	11	1.34	0.00	8.6E-05	9.37E-04	1.15E-04	0
IT	M-T-NaOCl-50-AC-I-I	MIX	1600	10	Cl2	3000	1100	—	11	0.99	0.00	5.0E-07	5.49E-06	4.99E-07	0
IT	V-Cl2-H-0	MIX	5000	0.67	Cl2	3000	1200	—	11	1.34	0.00	6.0E-04	6.53E-03	8.04E-04	0
Scenarios from External Events Analysis															
OS	OS-EXT-BOIL-HW-2	BOF	1800	11	TOL	700	—	—	0.00	0.00	0.00	3.0E-04	0	0	0
OS	OS-EXT-BOIL-HW-3	BOF	1800	25	TOL	700	—	—	0.00	0.00	0.00	2.0E-04	0	0	0
OS	OS-EXT-BOIL-HW-4	BOF	1700	53	TOL	700	—	—	0.00	0.00	0.00	2.0E-04	0	0	0
OS	OS-EXT-BOIL-WS-3A	BOF	4300	11	TOL	1200	—	—	0.87	0.00	0.00	7.0E-04	6.09E-04	0	0
OS	OS-EXT-BOIL-SW-2A	BOF	34	12	PCBs	1600	700	—	2.72	0.00	0.00	3.0E-04	8.16E-04	0	0
OS	OS-EXT-BOIL-SW-2B	BOF	27	12	PCBs	1400	600	—	1.62	0.00	0.00	3.0E-04	4.86E-04	0	0

TABLE 4-2. (Continued)

			Release			Effect Radius (m)			Number Affected			Total Frequency (/yr)	Health Effects (per year)		
Area	Accident Scenario Code	Mechanism	Rate (g/s)	Dur. (min)	Chemical	Revers.	Irrev.	Lethal	Revers.	Irrev.	Lethal		Revers.	Irrev.	Lethal
					MAXIMUM:	15000	2600	900	320	8.8	0.31	TOTALS:	4.5E-01	1.3E-02	7.4E-05
													(1/2yr)	(1/80yr)	(1/14Myr)

Plant Area Abbreviations:

OD = Organic Drum Stg & Handling
OR = Organic Tank Truck Unloading
OS = Incinerator Tank Farm
ID = Inorganic Drum Stg & Handling
IR = Inorganic Tank Truck Unloading
IS = Phys/Chem Storage Tank Area
IT = Phys/Chem Treatment Bldg Vent
IT(AO) = Phys/Chem Aqueous Organic

Mechanism Abbreviations:

LPE = liquid pool evaporation
TCP = toxic combustion products
VAP = all-vapor release
MIX = mixing of incompatibles
RAD = thermal radiation (fire)
EXP = explosion blast effects
BOF = boiloff (tank engulfed in fire)
NTR = entrainment of unburned material with combustion products in fire

Chemical Abbreviations:

Cl2 = chlorine
COCl2 = phosgene
HCl = hydrogen chloride
H2S = hydrogen sulfide
NOx = nitrogen oxides
PCBs = polychlorinated biphenyls
PCDFs = polychlorinated dibenzofurans
SO2 = sulfur dioxide
TOL = toluene

TABLE 4-3. INDIVIDUAL RISK SUMMARY FOR FENCELINE LOCATION

Area	Scenario Code	Mechanism	Release			Effect Radius (m)			Maximum Effect Probability			Total Frequency (/yr)	Individual Risk (effects/yr)		
			Rate (g/s)	Dur. (min)	Chemical	Revers.	Irrev.	Lethal	Revers.	Irrev.	Lethal		Revers.	Irrev.	Lethal
Organic Drum Storage and Handling Building — toxic combustion product and entrainment scenarios															
OD	L-HW-A-10-0-A	TCP	200	1 9	HCl	700	250	—	0.055	0.000	0.000	9.1E-06	4.99E-07	0	0
OD	L-HW-B-20-0-A	TCP	400	1.9	HCl	900	500	150	0.080	0.018	0.000	2.2E-03	1.72E-04	3.87E-05	0
OD	L-HW-C-50-3-A	TCP	56	30	HCl	600	—	—	0.037	0.000	0.000	6.2E-03	2.29E-04	0	0
OD	L-HW-D-100-1-A	TCP	670	5	HCl	1800	700	—	0.151	0.056	0.000	6.5E-06	9.83E-07	3.58E-07	0
OD	L-HW-D-80-0-A	TCP	1600	2.4	HCl	1800	1000	375	0.151	0.090	0.000	1.3E-06	1.95E-07	1.16E-07	0
OD	L-HW-E-160-0-A	TCP	3200	2.4	HCl	2400	1400	700	0.186	0.123	0.055	1.0E-08	1.86E-09	1.23E-09	5.50E-10
OD	L-HW-G-1000-2-A	TCP	3300	10	HCl	5000	2600	900	0.291	0.196	0.080	6.5E-06	1.89E-06	1.28E-06	5.21E-07
OD	L-HW-G-1000-3-A	TCP	1100	30	HCl	4500	900	200	0.274	0.080	0.000	3.7E-03	1.02E-03	2.98E-04	0
OD	0-OR-44(HW)	TCP	3800	2	HCl	2400	1400	700	0.186	0.123	0.055	1.7E-06	3.20E-07	2.12E-07	9.46E-08
OD	0-OR-44(SW)	TCP	6.4	2.8	COCl2	1000	700	—	0.090	0.055	0.000	1.0E-08	9.00E-10	5.50E-10	0
OD	0-OR-44(SW)	NTR	94	2.8	PCBs	1800	1400	—	0.151	0.123	0.000	1.0E-08	1.51E-09	1.23E-09	0
OD	0-OR-46(HW)	TCP	5100	15	HCl	9000	1800	600	0.403	0.151	0.037	1.7E-07	6.93E-08	2.60E-08	6.36E-09
Organic Tank Truck Unloading Area — toxic combustion product and entrainment scenarios															
OR	L-HW-B-17-0-A	TCP	350	2.2	HCl	1000	600	150	0.094	0.041	0.000	1.4E-04	1.33E-05	5.82E-06	0
OR	L-HW-B-29-1-A	TCP	130	5	HCl	650	—	—	0.050	0.000	0.000	7.1E-05	3.55E-06	0	0
OR	L-HW-C-17-0-A	TCP	340	5.6	HCl	900	350	—	0.084	0.000	0.000	8.1E-06	6.85E-07	0	0
OR	L-HW-C-46-3-A	TCP	58	30	HCl	600	—	—	0.041	0.000	0.000	7.5E-03	3.05E-04	0	0
OR	L-HW-C-50-2-A	TCP	170	10	HCl	1400	300	—	0.126	0.000	0.000	1.6E-02	2.00E-03	0	0
OR	L-HW-D-26-2-A	TCP	330	10	HCl	900	350	—	0.084	0.000	0.000	1.0E-08	8.40E-10	0	0
OR	L-HW-D-64-1-A	TCP	670	5	HCl	1800	725	300	0.152	0.062	0.000	1.9E-06	2.86E-07	1.17E-07	0
OR	L-HW-E-29-1-A	TCP	590	13	HCl	1200	450	—	0.111	0.008	0.000	4.1E-06	4 52E-07	3.26E-08	0
OR	L-HW-F-54-3-A	TCP	560	30	HCl	2600	600	—	0.194	0.041	0.000	1.0E-08	1.94E-09	4.10E-10	0
OR	L-HW-F-64-1-A	TCP	1300	15	HCl	2000	800	250	0.163	0.072	0.000	1.1E-05	1.84E-06	8.14E-07	0
OR	L-HW-G-75-3-A	TCP	1100	30	HCl	4500	900	250	0.267	0.084	0.000	1.0E-08	2.67E-09	8.40E-10	0
OR	L-HW-G-92-0-A	TCP	1900	21	HCl	7000	1400	350	0.342	0.126	0.000	9.2E-04	3.15E-04	1.16E-04	0
OR	L-HW-H-107-3-A	TCP	2200	35	HCl	15000	2200	450	0.513	0.174	0.008	4.3E-04	2.20E-04	7.45E-05	3.42E-06
OR	L-HW-H-131-3-A	TCP	2200	30	HCl	8000	1400	400	0.367	0.126	0.000	1.0E-08	3.67E-09	1.26E-09	0
OR	L-HW-H-152-0-A	TCP	3100	25	HCl	12500	1800	450	0.466	0.152	0.008	5.3E-05	2.47E-05	8.04E-06	4.23E-07
OR	L-ON-F-50-0-A	TCP	220	9	HCl	700	250	—	0.059	0.000	0.000	3 2E-03	1 89E-04	0	0
OR	L-ON-H-28-1-A	TCP	44	5	COCl2	1600	850	—	0.140	0.078	0.000	1.0E-02	1 40E-03	7.78E-04	0

TABLE 4-3. (Continued)

Area	Accident Scenario Code	Mechanism	Release Rate (g/s)	Release Dur. (min)	Release Chemical	Effect Radius (m) Revers.	Effect Radius (m) Irrev.	Effect Radius (m) Lethal	Maximum Effect Probability Revers.	Maximum Effect Probability Irrev.	Maximum Effect Probability Lethal	Total Frequency (/yr)	Individual Risk (effects/yr) Revers.	Individual Risk (effects/yr) Irrev.	Individual Risk (effects/yr) Lethal
OR	L-SW-C-17-0-A	NTR	0.9	7	PCBs	850	300	—	0.078	0.000	0.000	4.0E-08	3.12E-09	0	0
OR	L-SW-C-50-3-A	NTR	2.2	30	PCBs	450	—	—	0.008	0.000	0.000	8.7E-06	6.99E-06	0	0
OR	L-SW-D-64-1-A	TCP	1.0	5	COCl2	400	300	—	0.000	0.000	0.000	4.0E-07	0.00E+00	0	0
OR	L-SW-D-64-1-A	NTR	26	5	PCBs	700	500	—	0.059	0.023	0.000	4.0E-07	2.36E-08	5.43E-10	0
OR	L-SW-E-29-1-A	NTR	15	17	PCBs	1400	600	—	0.126	0.041	0.000	2.0E-08	2.52E-09	1.03E-10	0
OR	L-SW-F-64-1-A	NTR	34	20	PCBs	4000	900	—	0.250	0.084	0.000	8.0E-07	2.00E-07	1.68E-08	0
OR	L-SW-H-107-3-A	TCP	6	30	COCl2	600	200	—	0.041	0.000	0.000	2.1E-06	8.61E-08	0	0
OR	L-SW-H-107-3-A	NTR	87	30	PCBs	5000	1600	—	0.284	0.140	0.000	2.1E-06	5.96E-07	8.35E-08	0
OR	L-SW-H-152-0-A	TCP	5.4	33	COCl2	900	300	—	0.084	0.000	0.000	2.6E-05	2.18E-06	0	0
OR	L-SW-H-152-0-A	NTR	80	33	PCBs	8000	2400	—	0.367	0.184	0.000	2.6E-05	9.54E-06	1.76E-06	0
OR	L-SW-H-415-0-A	TCP	2.2	12	PCDFs	600	600	—	0.041	0.041	0.000	1.0E-08	4.10E-10	4.10E-10	0
OR	L-WS-I-152-3-A	TCP	72	46	SO2	500	150	—	0.023	0.000	0.000	1.0E-08	2.30E-10	0	0
Inorganic Drum Storage and Handling Building — toxic combustion product scenarios															
ID	L-HW-B-20-0-A	TCP	400	1.9	HCl	1000	600	150	0.082	0.030	0.000	2.1E-04	1.73E-05	6.33E-06	0
ID	L-HW-D-80-0-A	TCP	1600	2.4	HCl	2000	1000	600	0.154	0.082	0.030	1.3E-07	1.99E-08	1.06E-08	3.87E-09
Inorganic Tank Truck Unloading Area — toxic combustion product scenarios															
IR	L-HW-H-64-0-M	TCP	1300	59	HCl	9000	1600	350	0.370	0.128	0.000	2.1E-04	7.77E-05	2.69E-05	0
IR	L-NA-H-12-0-A	TCP	51	1.9	NOx	700	150	125	0.045	0.000	0.000	1.4E-08	6.08E-10	0	0
Inorganic Tank Truck Unloading Area — inadvertent mixing scenarios															
IR	M-T-AC-10-NaHS-H-I	MIX	470	60	H2S	2400	900	350	0.172	0.072	0.000	4.6E-04	7.86E-05	3.29E-05	0
IR	M-T-AC-10-NaHSO3-H-I	MIX	880	60	SO2	2000	800	600	0.152	0.059	0.031	4.6E-04	6.96E-05	2.70E-05	1.42E-06
IR	M-T-AC-10-NaOCl-H-I	MIX	490	60	Cl2	3500	1400	700	0.218	0.115	0.045	4.6E-04	9.98E-05	5.27E-05	2.06E-05
IR	M-T-FeCl3-10-NaHS-H-I	MIX	1200	5	H2S	2400	1400	475	0.172	0.115	0.002	8.8E-06	1.51E-06	1.01E-06	1.75E-08
IR	M-T-FeCl3-10-NaHSO3-H-I	MIX	2200	5	SO2	3000	1600	475	0.198	0.128	0.002	1.0E-05	2.04E-06	1.32E-06	2.06E-08
IR	M-T-FeCl3-10-NaOCl-H-I	MIX	820	5	Cl2	3500	1600	450	0.218	0.128	0.001	1.1E-05	2.33E-06	1.37E-06	1.07E-08
IR	M-T-H2SO4-10-NaHS-H-I	MIX	3300	5	H2S	4000	2000	825	0.236	0.152	0.063	1.6E-04	3.81E-05	2.46E-05	1.02E-05
IR	M-T-H2SO4-10-NaHSO3-H-I	MIX	6200	5	SO2	5000	2200	825	0.266	0.162	0.063	1.6E-04	4.40E-05	2.66E-05	1.03E-05
IR	M-T-H2SO4-10-NaOCl-H-I	MIX	3400	5	Cl2	7000	2600	850	0.323	0.181	0.066	1.6E-04	5.30E-05	2.97E-05	1.08E-05
IR	M-T-NaHS-10-FeCl3-H-I	MIX	1000	5	H2S	2200	1200	450	0.162	0.100	0.001	4.4E-06	7.18E-07	4.43E-07	4.43E-09

TABLE 4-3. (Continued)

Area	Scenario Code	Mech-anism	Release Rate (g/s)	Release Dur. (min)	Release Chem-ical	Effect Radius (m) Revers.	Effect Radius (m) Irrev.	Effect Radius (m) Lethal	Maximum Effect Probability Revers.	Maximum Effect Probability Irrev.	Maximum Effect Probability Lethal	Total Frequency (/yr)	Individual Risk (effects/yr) Revers.	Individual Risk (effects/yr) Irrev.	Individual Risk (effects/yr) Lethal
IR	M-T-NaHS-10-H2SO4-H-I	MIX	1000	5	H2S	2200	1200	450	0.162	0.100	0.001	5.5E-06	8.89E-07	5.49E-07	5.49E-09
IR	M-T-NaHSO3-10-FeCl3-H-I	MIX	850	5	SO2	2000	725	—	0.152	0.048	0.000	2.2E-04	3.39E-05	1.07E-05	0
IR	M-T-NaHSO3-10-H2SO4-H-I	MIX	850	5	SO2	2000	725	—	0.152	0.048	0.000	2.2E-04	3.42E-05	1.08E-05	0
IR	M-T-NaOCl-10-Fe[illegible]3-H-I	MIX	330	5	Cl2	2400	725	—	0.172	0.048	0.000	2.8E-04	4.73E-05	1.32E-05	0
IR	M-T-NaOCl-10-H2SO4-H-I	MIX	330	5	Cl2	2400	725	—	0.172	0.048	0.000	2.8E-04	4.76E-05	1.33E-05	0
Phys/Chem Storage Tank Area — toxic combustion product scenarios															
IS	L-NA-I-165-0-A	TCP	700	0.34	NOx	800	350	300	0.063	0.000	0.000	9.9E-03	6.24E-04	0	0
IS	L-UIN-H-150-0-A	TCP	750	0.22	SO2	450	—	—	0.000	0.000	0.000	1.6E-03	0	0	0
Phys/Chem Storage Tank Area — inadvertent mixing scenarios															
IS	M-T-NaHS-45-AC-I-I	MIX	4400	6	H2S	5000	2200	850	0.281	0.168	0.069	7.9E-06	2[illegible]06	1.33E-06	5.44E-07
IS	M-T-NaHSO3-45-AC-I-I	MIX	2500	7	SO2	3500	1800	450	0.227	0.145		9.5E-06	2.15E-06	1.38E-06	0
IS	M-T-NaOCl-45-AC-I-I	MIX	1400	18	Cl2	9000	2550	800	0.389	0.186	0.063	9.9E-06	3.84E-06	1.84E-06	6.22E-07
Phys/Chem Treatment Building — inadvertent mixing and process deviation/vapor release scenarios															
IT	M-T-NaHS-50-AC-I-I	MIX	4900	5.5	H2S	5000	2200	600	0.268	0.160	0.025	3.1E-07	8.25E-08	4.93E-08	7.70E-09
IT	M-T-NaHSO3-10-AC-I-I	MIX	570	30	SO2	1000	—	—	0.077	0.000	0.000	8.6E-05	6.62E-06	0	0
IT	M-T-NaHSO3-50-AC-I-I	MIX	2800	6	SO2	3500	1600	—	0.217	0.126	0.000	4.7E-07	1.02E-07	5.90E-08	0
IT	M-T-NaOCl-15-AC-I-I	MIX	470	33	Cl2	3000	1200	400	0.197	0.096	0.000	8.6E-05	1.69E-05	8.26E-06	0
IT	M-T-NaOCl-50-AC-I-I	MIX	1600	10	Cl2	3000	1100	—	0.197	0.087	0.000	5.0E-07	9.93E-08	4.38E-08	0
IT	V-Cl2-H-0	MIX	5000	0.67	Cl2	3000	1200	—	0.197	0.096	0.000	6.0E-04	1.18E-04	5.76E-05	0
Scenarios from External Events Analysis															
OS	OS-EXT-BOIL-HW-2	BOF	1800	11	TOL	700	—	—	0.048	0.000	0.000	3.0E-04	1.44E-05	0	0
OS	OS-EXT-BOIL-HW-3	BOF	1800	25	TOL	700	—	—	0.048	0.000	0.000	2.0E-04	9.60E-06	0	0
OS	OS-EXT-BOIL-HW-4	BOF	1700	53	TOL	700	—	—	0.048	0.000	0.000	2.0E-04	9.60E-06	0	0
OS	OS-EXT-BOIL-WS-3A	BOF	4300	11	TOL	1200	—	—	0.103	0.000	0.000	7.0E-04	7.21E-05	0	0
OS	OS-EXT-BOIL-SW-2A	BOF	34	12	PCBs	1600	700	—	0.131	0.048	0.000	3.0E-04	3.93E-05	1.44E-05	0
OS	OS-EXT-BOIL-SW-2B	BOF	27	12	PCBs	1400	600	—	0.118	0.034	0.000	3.0E-04	3.54E-05	1.02E-05	0

TABLE 4-3. (Continuing)

			Release			Effect Radius (m)			Maximum Effect Probability			Total	Individual Risk (effects/yr)		
Area	Scenario Code	Mechanism	Rate (g/s)	Dur. (min)	Chemical	Revers.	Irrev.	Lethal	Revers.	Irrev.	Lethal	Frequency (/yr)	Revers.	Irrev.	Lethal
					MAXIMUM:	15000	2600	900	0.513	0.196	0.080	TOTALS:	7.5E-03	1.7E-03	7.2E-05
													(1/130yr)	(1/600yr)	(1/14Myr)

Plant Area Abbreviations:

OD = Organic Drum Stg & Handling
OR = Organic Tank Truck Unloading
OS = Incinerator Tank Farm
ID = Inorganic Drum Stg & Handling
IR = Inorganic Tank Truck Unloading
IS = Phys/Chem Storage Tank Area
IT = Phys/Chem Treatment Bldg Vent
IT(AO) = Phys/Chem Aqueous Organic

Mechanism Abbreviations:

LPE = liquid pool evaporation
TCP = toxic combustion products
VAP = all-vapor release
MIX = mixing of incompatibles
RAD = thermal radiation (fire)
EXP = explosion blast effects
BOF = boiloff (tank engulfed in fire)
NTR = entrainment of unburned material with combustion products in fire

Chemical Abbreviations:

Cl2 = chlorine
COCl2 = phosgene
HCl = hydrogen chloride
H2S = hydrogen sulfide
NOx = nitrogen oxides
PCBs = polychlorinated biphenyls
PCDFs = polychlorinated dibenzofurans
SO2 = sulfur dioxide
TOL = toluene

4.1 Offsite Reversible Health Effect Risk

4.1.1 Definition

A "reversible health effect" is an effect such as coughing which is considered more serious than odor or minor irritation, but not unbearable or permanently debilitating; i.e., an affected person's health returns to normal soon after the exposure stops.

4.1.2 Societal Risk

As shown in Table 4-1, the present analysis indicates a total risk of 0.45 offsite reversible health effect per year, or a weighted average of about one in 2 years. This total risk is the sum of societal risk measures (event frequency times number of people affected) calculated for each accident scenario code having potential offsite reversible health effect consequences. This result is based on the present population distribution around the location of the proposed Ontario Waste Management Corporation (OWMC) Facility; it should be noted that any significant future residential construction within the potentially affected area would change the offsite risk results.

Presented in Figure 4-1 is the offsite reversible health effect risk shown as a complementary cumulative distribution function (f-N curve). It can be seen from this figure that the maximum likely number of reversible health effects per accidental release event is about 300. This corresponds to the Accident Scenario Code L-HW-H-107-3-A (as listed in Table 4-2) with reversible health effects extending to 15 km from the main process buildings, compared to the nearest offsite persons presently living about 0.7 km from this location. The predicted frequency of an event occurring with this magnitude of effects is about one chance in 2,300 per year of facility operation.

The total reversible health effect point risk estimate of 0.45 per year (from Table 4-1) can be divided by the total frequency of accidental events having offsite effects of 0.068 per year (equivalent to the sum of the "Frequency" column in Table 4-2) to determine that the overall average number of revers-ible health effects is about 7 per

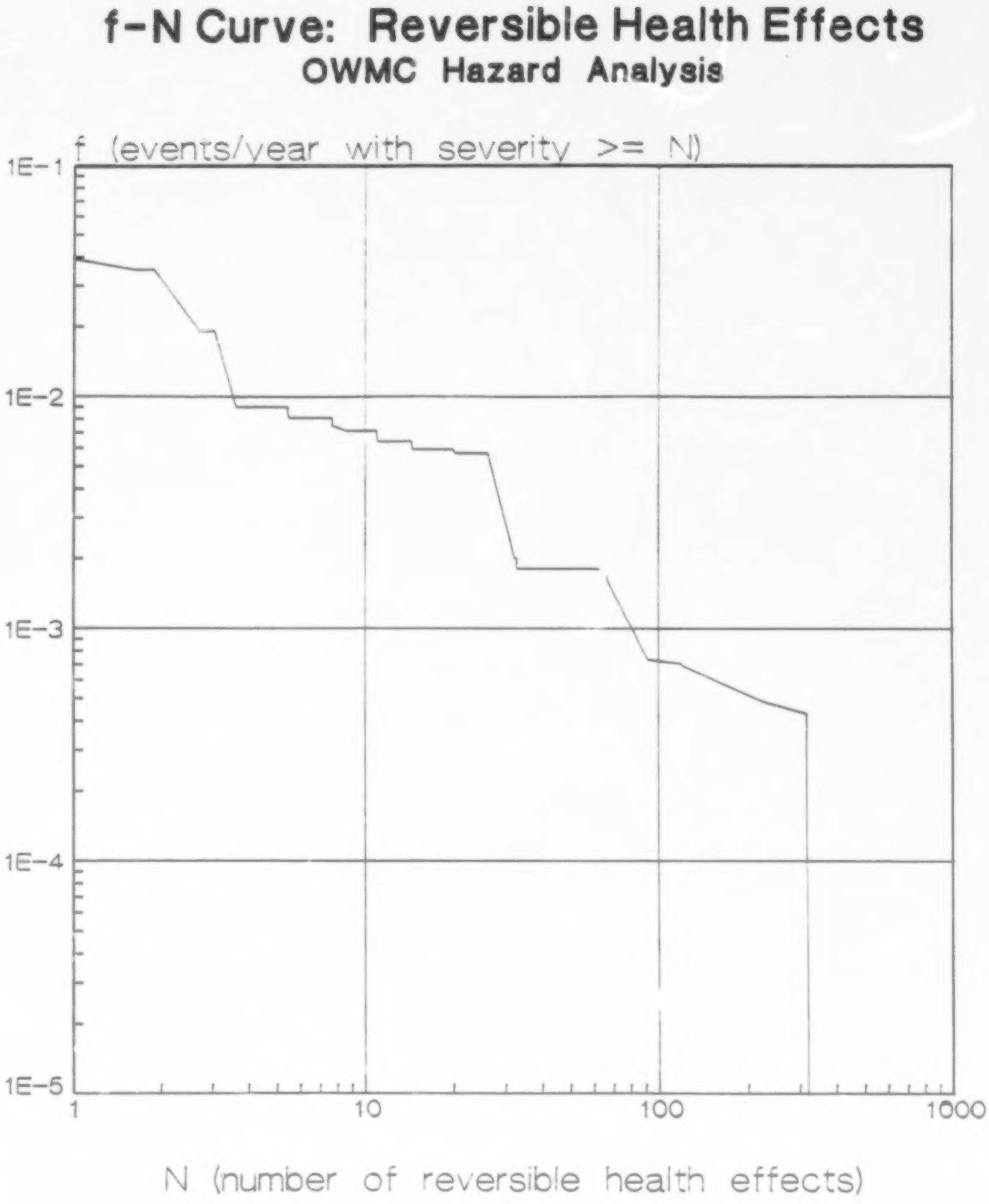


FIGURE 4-1. f-N CURVE FOR OFFSITE REVERSIBLE HEALTH EFFECTS

accidental event (= 0.45 ÷ 0.068). In other words, if an accidental event occurs at the facility which is severe enough to affect people living offsite, then the average number of people affected offsite would be about 7 at the reversible health effect level.

4.1.3 Individual Risk

The maximum individual risk of offsite reversible health effects was calculated at the fenceline location of the proposed site (even though there are no residents presently adjacent to the fenceline). As indicated in Table 4-1, the present analysis indicates a maximum individual risk of reversible health effects of 0.008 per year, or one chance in 130 per year. The consequence analysis takes into account wind direction probabilities and plume widths, and determines the highest-risk location around the entire perimeter of the proposed facility for each offsite scenario. Thus, the analysis indicates that if a person lived all the time at the fenceline of the proposed facility at the highest-risk location around the perimeter of the site, the likelihood of that person experiencing a reversible health effect as a result of an onsite accident (with no credit given for mitigating factors such as being indoors) would be one chance in 130 per year.

4.2 Offsite Irreversible Health Effect Risk

4.2.1 Definition

An "irreversible health effect" is nonlethal and not severe enough to cause permanent disability such that a person could not perform normal job functions, but severe enough to cause some long-term impairment such as partial loss of lung capacity. Exposure to an irreversible health effect level should not prevent a person from being able to escape from an affected area.

4.2.2 Societal Risk

As shown in Table 4-1, the present analysis indicates a total risk of 0.013 offsite irreversible health effect per year, or a weighted average of one per 80 years. This total risk is the sum of societal risk measures (event frequency times number of people affected) calculated for each accident scenario code having potential offsite irreversible health effect consequences. This result is based on the present population distribution around the location of the proposed OWMC Facility.

Presented in Figure 4-2 is the offsite irreversible health effect risk shown as a cumulative distribution function (f-N curve). It can be seen from this figure that the maximum likely number of irreversible health effects per accidental release event is about 9. This corresponds to three accident scenario codes (as listed in Table 4-2) with irreversible health effects extending to about 2,600 m from the main process buildings. The predicted frequency of an event occurring with this magnitude of effects is about one chance in 6,000 per year of facility operation.

The total irreversible health effect point risk estimate of 0.013 per year (from Table 4-1) can be divided by the total frequency of accidental events potentially having offsite irreversible effects of 0.022 events per year (equivalent to the sum of the "Frequency" column in Table 4-2 for all accident scenario codes showing irreversible health effects beyond 400 m) to determine that the overall average number of irreversible health effects per accidental event is about 0.6 (= 0.013 ÷ 0.022). In other words, if an accidental event occurs at the treatment facility which is severe enough for irreversible effects to extend beyond the fenceline, then the average number of people affected offsite would be about one person in every two events at the irreversible health effect level.

4.2.3 Individual Risk

The maximum individual risk of offsite irreversible health effects was calculated at the fenceline location of the proposed site (even though there are no residents presently adjacent to the fenceline). As shown in Table 4-1, the present analysis indicates a maximum individual risk of

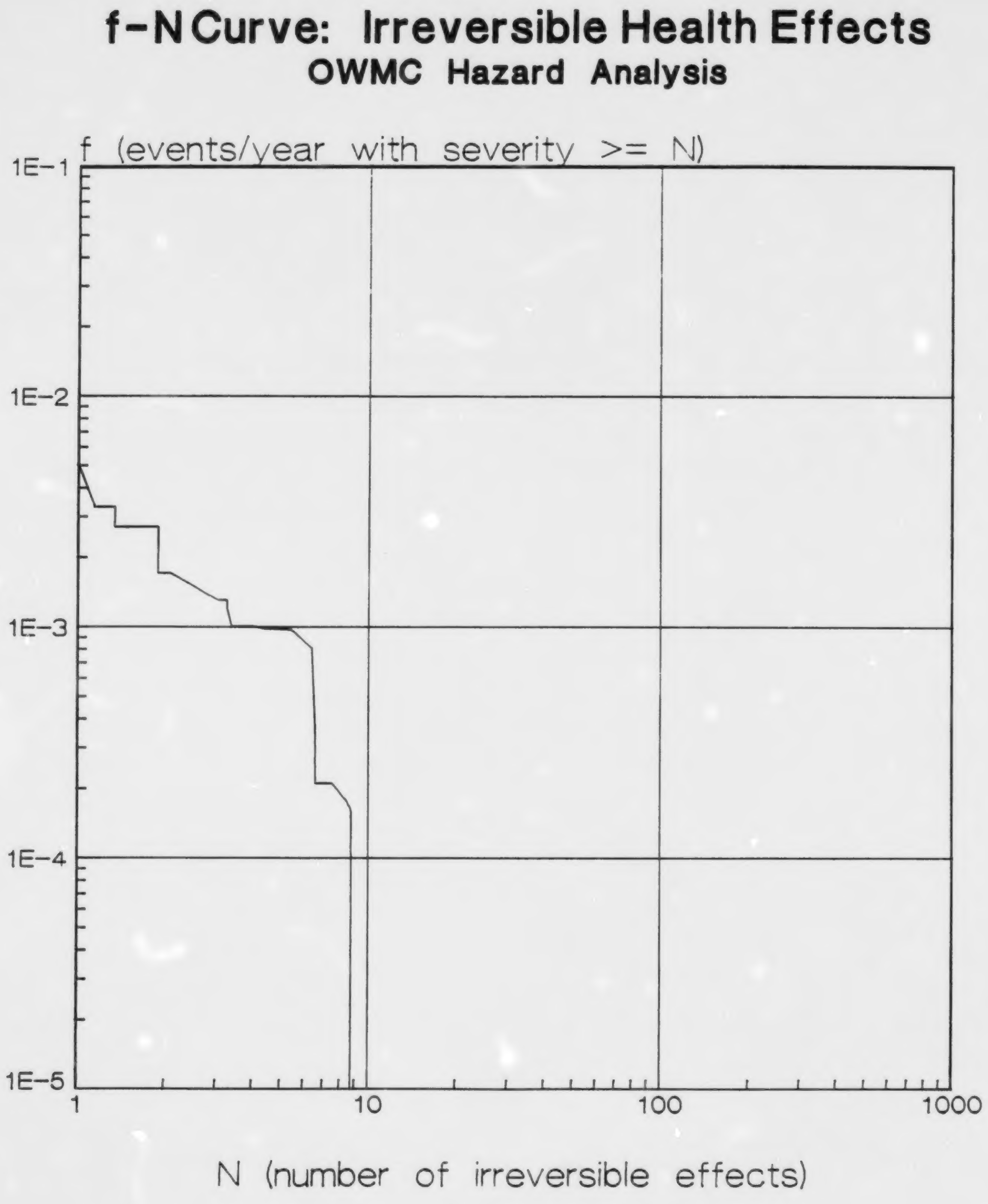


FIGURE 4-2. f-N CURVE FOR OFFSITE IRREVERSIBLE HEALTH EFFECTS

irreversible health effects of 0.0017 per year, or about one chance in 600 per year. As for reversible health effects, the consequence analysis takes into account wind direction probabilities and plume widths, and determines the highest-risk location around the entire perimeter of the proposed facility for each offsite scenario. Thus, the analysis indicates that if a person lived all the time at the fenceline of the proposed facility at the highest-risk location around the perimeter of the site, the likelihood of that person experiencing an irreversible health effect as a result of an onsite accident (with no credit given for mitigating factors such as being indoors) would be about one chance in 600 per year.

4.3 Offsite Lethal Health Effect Risk

4.3.1 Definition

A "lethal health effect" is severe enough to cause permanent disability or even fatality to a person in a residential population. The scenarios having consequences severe enough to cause an offsite lethal health effect involve the release of gases which generally have good warning properties and which affect the pulmonary system (hydrogen chloride, hydrogen sulfide, sulfur dioxide, and chlorine).

4.3.2 Societal Risk

As shown in Table 4-1, the present analysis indicates a total risk of 7×10^{-5} offsite lethal health effect per year, or a weighted average of one per 14,000 years. This total risk is the sum of societal risk measures (event frequency times number of people affected) calculated for each scenario having potential offsite lethal health effect consequences. This result is based on the present population distribution around the location of the proposed OWMC Facility.

Presented in Figure 4-3 is the offsite lethal health effects risk shown as a cumulative distribution function (f-N curve). It can be seen from this figure that the maximum likely number of lethal health effects per accidental release event is one; i.e., if an accidental event occurs onsite with lethal effects offsite, then no more than one person would likely be

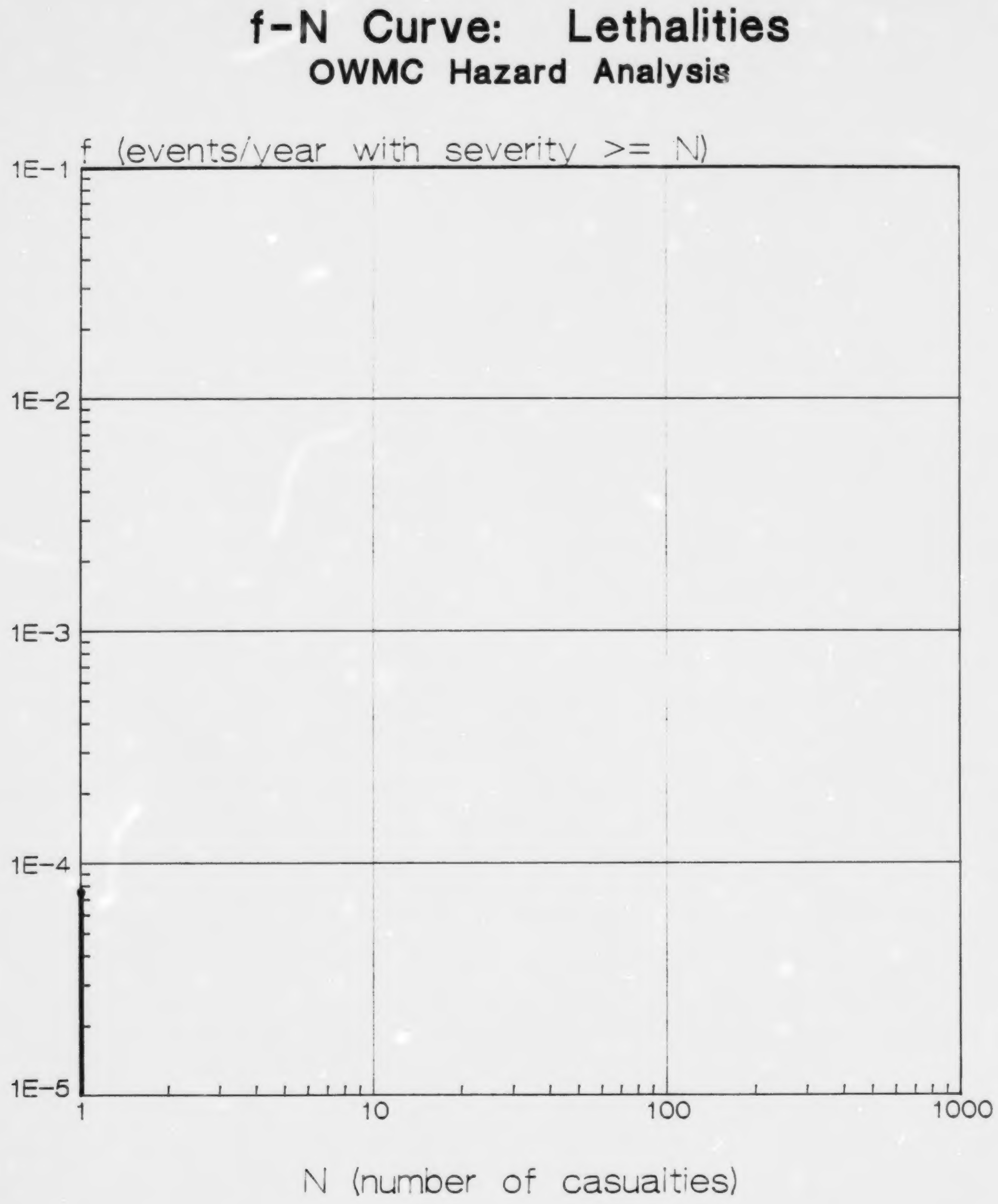


FIGURE 4-3. f-N CURVE FOR OFFSITE LETHAL HEALTH EFFECTS

affected. Under the unfavorable (i.e., conservative) meteorological conditions used in this study, the analysis indicates that the maximum distance to which lethal health effects extend is 900 m from the proposed Organic Drum Storage and Handling Building location or 850 m from the proposed Inorganic Tank Truck Unloading Area or Physical/Chemical Storage Tank Area locations.

The total lethal health effect point risk estimate of 7 x 10^{-5} per year (from Table 4-1) can be divided by the total frequency of accidental events potentially having offsite lethal effects of 0.002 per year (equivalent to the sum of the "Frequency" column in Table 4-2 for all accident scenario codes showing lethal health effects beyond 400 m) to determine that the overall average number of lethal health effects per accidental event is about 0.04 (= (7 x 10^{-5}) ÷ 0.002). In other words, if an accidental event occurs at the treatment facility which is severe enough for lethal effects to extend beyond the fenceline, then the average number of people affected offsite would be about one person in every 30 events at the lethal health effect level.

4.3.3 Individual Risk

The maximum individual risk of offsite lethal health effects was calculated at the fenceline location of the proposed site (even though there are no residents presently adjacent to the fenceline). As shown in Table 4-1, the present analysis indicates a maximum individual risk of lethal health effects of 7 x 10^{-5} per year, or one chance in 14,000 per year. As for reversible health effects, the consequence analysis takes into account wind direction probabilities and plume widths, and determines the highest-risk location around the entire perimeter of the proposed facility for each offsite scenario. Thus, the analysis indicates that if a person lived all the time at the fenceline of the proposed facility at the highest-risk location around the perimeter of the site, the likelihood of that person experiencing a lethal health effect as a result of an onsite accident (with no credit given for mitigating factors such as being indoors) would be one chance in 14,000 per year.

4.4 Discussion of Important Scenarios

As indicated in Tables 4-2 and 4-3, scenarios with the potential for offsite health effects were identified from each of the main process areas. Brief descriptions of the most important scenarios are included as Appendix H.

4.4.1 Inadvertent Mixing Scenarios

The scenarios showing the highest offsite risk (both societal and individual) were those associated with inadvertent mixing of incompatible materials causing generation and release of toxic gases. These inadvertent mixing scenarios all have the first letter "M-" in the accident scenario code list of Tables 4-2 and 4-3. All of the inadvertent mixing scenarios having offsite consequences were accidents involving the unloading of a reagent or waste into the wrong tank, or having the wrong reagent or waste in a tank before transfer of a second material. Event frequencies for the unloading scenarios were determined using fault trees to combine the necessary operator error and equipment failure probabilities with the various truck receipt frequencies. Two general accident scenarios were the unloading of a reagent or waste into the wrong tank in the inorganic tank truck unloading area, and an incoming reagent or waste truck containing a different material than the material listed on the shipping manifest.

4.4.2 Toxic Combustion Products

Also prominent in the scenarios showing offsite risk were those associated with the spillage and ignition of wastes resulting in toxic combustion products being emitted from the vent of the building enclosure. Since the building vents are not designed to allow the vapors to escape the building wake effect, the toxic combustion vapors would be brought back to ground level on the downwind side of the building. The release was modeled as originating at one-half the height, with an initial plume width equal to the building width.

4.4.3 Entrainment of PCBs

Scenarios involving segregated wastes were modeled using a waste composition of 1 percent PCBs in oil, which is a segregated waste example composition taken from the Canviro Data Base (Monenco, 1988). For scenarios where a segregated waste stream could be involved in a pool fire, it was conservatively assumed that all of the PCBs in the waste stream could be volatilized and entrained with the combustion products (and thus not be consumed in the fire), since PCBs do not burn as readily as most organics. These scenarios were given the mechanism code "NTR" in Tables 4-2 and 4-3. Even with the conservative assumption of total entrainment, all entrainment scenarios together accounted for only 0.6 percent of the total reversible health risk, 1.6 percent of the total irreversible health effects risk, and 0 percent of the total lethal health effects risk (no offsite lethal health effects).

4.5 Comparisons With Other Risks

4.5.1 Societal Risk

While the OWMC Hazard Analysis estimates the societal risk for all three levels of health effects, there are only a few comparisons available. One which can be used is the societal risk goal which The Netherlands has put into law. This law requires all facilities to estimate their risk, and to make facility changes if the risk is above a specific limit. Further, it can be said that this goal is the most stringent currently being imposed by any legislative body in the world. The estimated societal risk for the OWMC Treatment Facility is such that if the facility, with its 400-m buffer zone and surrounding population density, were located in The Netherlands it would meet their societal criteria such that no facility modifications would be required.

Another way of looking at the societal risk is to compare the expected fatalities for a group of people over time in the vicinity of the facility. Specifically, for the population currently living within the

Property Value Protection Zone over the next 70 years (OWMC Treatment Facility lifetime), the expected fatalities by cause are

Cause	Fatalities
Motor vehicles	5.8
Farming accidents*	2.1
House fires	0.6
Firearm accidents	0.2
Electrocution	0.05
Lightning	0.009

When the OWMC Treatment Facility is operating, it will add to the risk an expected number of fatalities of 0.005 over the 70-year period. Note that the expected fatalities from the OWMC Treatment Facility is about one-half of those expected from lightning, and less than one-thousandth of those expected from motor vehicles.

4.5.2 Individual Risk

The OWMC Hazard Analysis estimated the acute individual risk of fatality for the "maximum exposed individual" to be similar to the risk of the average person being killed by accidental falls. It may also be stated that this individual risk level is similar to the estimated risk from a coal-fired power plant and less than the estimated risk from refineries at Canvey Island**. This risk level is also below the risk level for individuals summed over all accidents they are normally exposed to (car, farm, airplane, etc.). Also, the OWMC Hazard Analysis identified no accident scenarios which have fatalities outside of the Property Value Protection Zone.

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* It is assumed that only one in four people in the population are actually involved in farming, and hence exposed to farm accidents.

** Canvey Island is a dense complex of chemical and petrochemical manufacturing and storage facilities adjacent to a populated area in Great Britain. It was the site of the first detailed, comprehensive risk assessment of a nonnuclear industrial complex.

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GLOSSARY

Accident, Accident Scenario, Accident Sequence, Accident Event Sequence	A specific unplanned event or sequence of events with a specific undesirable consequence.
Accident Scenario Code	A unique code that represents one or more accident scenarios that have several attributes in common including the same or nearly the same initial accidental event and the same or nearly the same consequence. By using an accident scenario code the consequences of the entire group of accident scenarios can be analyzed at the same time.
Accident Cause	A mechanical failure, operational error, or external event which can lead to an accident if protection measures and protective systems fail to bring the process under control.
Accident Event Sequence	See Accident.
Accident Sequence	See Accident.
Acute Exposure	A short-term, accidental exposure to a toxic agent in a single episode that is unlikely to recur.
Acute Hazard	The potential for injury or damage to occur as a result of an instantaneous or short-duration exposure to the effects of an undesirable event such as an accidental spill of toxic material.
Acute Health Effects	The immediate or near-term effect of a short-term exposure to a toxic agent, heat radiation, caustic chemical, overpressure, missile impacts, etc.
Acute Risk	The potential for acute health effects from an accident measured in terms of the severity of effects of the accident and the likelihood of the accident occurring.
Basic Event	A mechanical failure or operational error in a system which can either be an accident cause or a protective system fault.
Boolean Expression	A relationship from probability analysis that expresses the likelihood of an

Boolean Expression (Continued)	accident scenario in terms of the likelihoods of the individual events that define the accident.
Bounding Analysis	An analysis which uses conservative or worst-case values for one or more of the parameters such that the result represents an upper bound or upper limit to the risk from that source.
Chronic Exposure	A frequent or continuous exposure to an environmental condition or a toxic agent over an unspecified, but generally lengthy, period of time.
Chronic Hazard	The potential for injury or damage to occur as a result of prolonged exposure to an undesirable condition (e.g., smoking, with the potential for lung cancer).
Chronic Risk	The potential for chronic health effects from an accident or process upset measured in terms of the effects of the severity of the accident and the likelihood of the accident occurring.
Consequence	The result or results of an accident (accident event sequence) in terms of the effects that are of most interest or concern to the hazard analysis. In this document the effects of most concern are offsite and onsite health effects to individuals and to society.
Cross-Reference	An association of a HAZOPS scenario with another scenario when its likelihood contributes to the likelihood of the other scenario. The cross-referenced scenarios may have been identified in different facility areas; e.g., if a valve fails shut and increases the presssure on a pump seal upstream and causes it to fail, the accidental release through the pump seal should be evaluated at the site of the pump. However, the likelihood of the valve failure downstream will contribute to the likelihood of the release at the pump site.
Deflagration	A chemical reaction such as the burning of a flammable vapor cloud in which the reaction proceeds through the mixture at less than sonic velocity. Damage from overpressure is generally less than from a detonation.

Detonation	A chemical reaction such as the explosive burning of a massive flammable vapor cloud in which the reaction proceeds through the mixture at sonic velocity or greater. Damage from overpressure and other blast effects is generally greater than from a deflagration.
Deviation	A change of a process parameter from its intended value identified in a HAZOPS as a potential initial accidental event that could result in an undesirable consequence.
Event Tree	A logic diagram which describes all identified sequences of events (accidents). The outcomes of both the success and the failure of successive events are displayed starting with an initial accidental event and concluding with the different consequences that might result from the initial accidental event. (Event trees are also used to study accident event sequences starting with accident causes.)
Event Tree Analysis	A probabilistic analysis of an event tree to identify and estimate the likelihood of each independent consequence.
External Event	An occurrence external to the system/plant/process which can have an effect on the process, such as an earthquake, tornado, or loss of external electric power.
External Event Analysis	An analysis of the potential consequences and the likelihood of an accident or plant upset initiated by an external event.
Facility Risk	The total risk represented by the consequences and likelihoods of all potential accidents and process upsets that might occur as a result of operation of a facility.
Failure Modes and Effects Analysis (FMEA)	A method used in hazard analysis for systematic and detailed examination of the components of a system to identify how they fail and the effect of the failure on system behavior. An FMEA can be performed by one person or by a team. The focus of the examination is on the equipment rather than the process and process parameters as in a HAZOPS.

Fault Tree	A logic diagram that relates all basic causes, and combinations of causes, and the success or failure of protective equipment and actions, that might lead to an initial accidental event.
Fault Tree Analysis	Probabilistic analysis of a fault tree to estimate the likelihood of the initial accidental event from the likelihoods of the contributing causes and the response of protective equipment and actions.
Guide Words	A set of modifying expressions such as "more of", "less of", "reverse" used in the HAZOPS method to suggest potential deviations of process parameters as the first step in identifying and evaluating potential process upsets or accidents.
Hazard	A characteristic of a system/plant/process that represents a potential for an accident that could have an undesirable consequence. Usually a significant quantity of a toxic or highly energetic material which, if accidentally released, could cause undesirable health effects.
Hazard Analysis	The use of systematic methods of analysis to identify and evaluate hazards and potential accidents and process upsets that might result in acute health effects and/or economic loss.
HAZOPS (Hazard and Operability Study)	A method used in hazard analysis for systematic and detailed examination of a process by a team knowledgeable of the process being examined and having experience in the use of HAZOPS for hazard analysis.
HAZOPS Scenario	A specific unplanned event or sequence of events identified in a HAZOPS. The scenario may or may not be equivalent to an accident scenario; i.e., it may or may not have an undesirable consequence.
IDLH	"Immediately Dangerous to Life and Health". Maximum airborne contaminant concentrations from which one could escape within 30 min without any escape-impairing symptoms or any irreversible health effects. Developed by the National Institute for Occupational Safety and Health (NIOSH).

Impact	The ultimate potential result of a hazardous event, expressed, depending on the particular application, in terms of injuries, fatalities, environmental or property damage, business interruption, etc.
Initial Accidental Event	An accidental event that will result in undesirable consequences unless systems or operations intervene to mitigate the consequences; e.g., a spill of flammable material that may or may not have undesirable consequences depending upon the implementation of alarms, a fire suppression system, etc.
Intermediate Event	An unintended event in an accident event sequence that is a part of the propagation of the accident from the initial accidental event to the ensuing impact.
Irreversible Health Effect	A health effect that is nonlethal, and not severe enough to cause permanent disability such that a person could not perform normal job functions, but severe enough to cause some long-term impairment such as partial loss of lung capacity. Exposure to an irreversible health effect level should not prevent a person from being able to escape from an affected area.
LD_{50}	A dose of a hazardous substance or agent which is lethal to 50 percent of a given population.
Likelihood	A measure of the expected frequency or probability with which an event, or a sequence of events, occurs. This may be expressed as a frequency (e.g., events per year), a probability of occurrence during a time interval (e.g., annual probability), or a conditional probability (e.g., probability of occurrence, given that a precursor event has occurred).
Measures of Risk	A statement of risk in terms that communicate the consequence level for (potential effect on) the parties of concern and the likelihood or frequency of that consequence. For example: risk of irreversible health effect to the "most exposed individual"; risk of irritation to population within 1,000 m of the release point.

Mitigation	The use of equipment and/or actions to respond to an accident event sequence by interfering with accident propagation and/or reducing the severity of the accident consequences.
Offsite Consequences	In this document, effects on individuals or society at or beyond the boundary of the proposed OWMC Facility location (fenceline).
Onsite Consequences	In this document, effects on employees or others within the boundary of the facility.
PEEL	"Public Emergency Exposure Limit" is the maximum concentration in air of a toxic material to which the public might be exposed without significant adverse impacts in the event of an accident.
PELs	"Permissible Exposure Limits" are similiar to "TLVs" (see below) but developed by the Occupational Safety and Health Administration (OSHA).
Preliminary Hazard Analysis	A qualitative survey of hazards and potential consequences to estimate the degree of hazard and prioritize areas of the facility for more detailed analysis.
Probability	An expression for the likelihood of occurrence of an event or an event sequence, the likelihood of failure of a component in response to a test or demand, or the likelihood of human error of commission or omission during an interval of time or in response to a given situation.
Process Parameters	The temperature, pressure, flow rate, or other variables in a process line or vessel which are measured and controlled.
Process Parameter Deviation	In the HAZOPS method, a change of a process parameter from the intended value or range of values at a particular point in the process.
Protective Systems	Systems such as a high pressure relief valve provided to protect against an initial accidental event such as an overpressure deviation in a vessel or pipe.

Qualitative Decision Criteria	Conservative limits on consequence levels, likelihood, and risk that are the basis for deciding whether identified potential accidents and process upsets can be eliminated from further consideration or require further analysis.
Quantitative Decision Criteria	Realistic limits on consequence levels, likelihood, and risk that are the basis for decisions on whether consequences and/or risk are acceptable or further risk reduction is necessary.
Reversible Health Effect	A health effect such as coughing which is considered more serious than odor or irritation, but is not unbearable or permanently debilitating; i.e., an affected person's health returns to normal soon after the exposure stops.
Risk	A measure of potential health effects (or economic loss) in terms of the probability of the health effects occurring and the magnitude of the health effects if they were to occur. In this document this can be described in terms of the likelihood of an accident or process upset and the severity of the consequences of the accident/upset. Risk can also refer to the combined risk of all potntial accidents/upsets. See Facility Risk.
Scenario Identifier	A unique identifier of an accident scenario by OWMC Treatment Facility Area and the number of the accident scenario identified in that area in a HAZOPS session, e.g., OS-1 for the first accident scenario identified in the Organic Storage (Incinerator Tank Farm) Area.
SPEGLs	"Short-Term Public Emergency Guidance Level". For exposures whose occurrence is expected to be rare in the lifetime of any one individual, the 60-min exposure concentration that reflects an acceptance of the statistical likelihood of a non-incapacitating reversible effect in an exposed population, while avoiding significant decrements in performance. Developed by the National Academy of Sciences (NAS).

STEL	"Short Term Exposure Limit". Time-weighted average for a 15-min period to which workers can be exposed without suffering from: (1) irritation, (2) chronic or irreversible tisssue damage, or (3) narcosis.
Task Analysis	An analytical process for determining the detailed performance required of people and equipment and the effects of environmental conditions, malfunctions, and other unexpected events on both. Within each task to be performed by people, behavioral steps are analyzed in terms of perceptions, decisions, and responses.
Templating	Using the detailed results and facility descriptions from HAZOPS scenarios developed and recorded in a HAZOPS session to develop HAZOPS scenarios for similiar operations that were not examined in a HAZOPS session.
TLV-C	"Threshold Limit Value-Ceiling" is the concentration in air that should not be exceeded during any part of the working exposure. Ceiling limits may supplement other limits or stand alone. Developed by the American Conference of Governmental Industrial Hygienists (ACGIH).
TLV-STEL	"Threshold Limit Value-Short-Term Exposure Limit" is a 15 min, time-weighted average concentration to which workers may be exposed up to four times per day with at least 60 minutes between successive exposures with no ill effect if the TLV-TWA (see below) is not exceeded. This limit supplements the TLV-TWA where there are recognized acute effects from a substance with toxic effects that result primarily from chronic exposures. Developed by the ACGIH.
TLV-TWA	"Threshold Limit Value-Time-Weighted Average". The time-weighted concentration limit for a normal 8-hr workday and a 40-hr workweek to which nearly all workers may be repeatedly exposed, day after day, without adverse effect. Developed by the ACGIH.

Typical Waste	A waste composition specified to represent the waste streams, in a given category, most likely to be received by the fFacility for treatment. A typical waste was specified for each waste category.
Unusual Waste	A waste chosen for sensitivity studies of the accident scenarios of most concern. These wastes will rarely be received but, because of the potential consequences if they are involved in an accident, may require special attention if they are received.
Waste Category	A type of waste, such as aqueous organic or inorganic acidic. All waste streams expected at the facility are expected to be in one of nine categories. See Table 2-6.
"What If" Analysis	A systematic method for identifying hazards and potential accidents/upsets that is used for analysis of familiar designs and operations. It is less suited for examining new designs and operations than the HAZOPS method.
WEELs	"Workplace Environmental Exposure Levels" are similiar to TLVs, but for materials not addressed by ACGIH or OSHA. Developed by the American Industrial Hygiene Association (AIHA).

APPENDIX A

OWMC FACILITY DESIGN DRAWINGS, DIAGRAMS, AND FLOWSHEETS USED IN HAZARD ANALYSIS

APPENDIX A

OWMC FACILITY DESIGN DRAWINGS, DIAGRAMS, AND FLOWSHEETS USED IN HAZARD ANALYSIS

Monenco Limited – Plant Layout Drawings

Drawing No.	Revision	Title
005000202	E	LF-9C Plant Layout
005000203	D	LF-9C Site Plan
504505413	B	Organic Drum Storage and Handling Building Conceptual Equipment Layout Plan
504505206	B	Organic Drum Storage and Handling Building Conceptual Equipment Layout Sections "A-A" and "B-B"
504505405	B	Incineration Tank Farm Conceptual Layout Plan
504505406	B	Organic Unloading and Storage Areas Conceptual Layout Plan
504505423	A	Organic Tank Truck Unloading Area Conceptual Equipment Layout Plan & Sections
504505423	B	Organic Tank Truck Unloading Area Conceptual Equipment Layout Plan & Sections
204202411	A	Incinerator Plant Conceptual Equipment Layout Plan
204202208	D	Incineration Plant Conceptual Equipment Layout Sections AA and BB
504505422	A	Inorganic Tank Truck Unloading Area Conceptual Equipment Layout Plan & Sections
504505420	B	Physical/Chemical Tank Storage Area Conceptual Equipment Layout Plan
504505412	B	Inorganic Drum Storage and Handling Building Conceptual Equipment Layout Plan & Sections
104101202	B	Physical/Chemical Treatment Plant Conceptual Equipment Layout Sections

Drawing No.	Revision	Title
104101404	B	Physical/Chemical Treatment Plant Conceptual Equipment Layout Ground Floor
104101405	B	Physical/Chemical Treatment Plant Conceptual Equipment Layout Mezzanine Level
104101406	B	Physical/Chemical Treatment Plant Conceptual Equipment Layout 2nd Floor
304303403	A	Solidification Plant Conceptual Equipment Layout Plan
304303204	A	Solidification Plant Conceptual Equipment Layout Sections A-A and B-B
304303205	A	Solidification Plant Conceptual Equipment Layout Sections C-C & D-D

Monenco Limited – Piping and Instrumentation Diagrams (P&IDs)

Drawing No.	Revision	Title
50353070	B	Organic Drum Handling Schematic
103100101	C	Phys/Chem P.F.D. Waste Storage
103100105	C	Phys/Chem P.F.D. Inorganic Waste Treatment System
103100201	C	Phys/Chem P&ID Inorganic Waste Neutralization/ Precipitation
103100202	C	Phys/Chem P&ID Inorganic Waste Oxidation/ Reduction
103100203	C	Phys/Chem P&ID Inorganic Waste Oxidation/ Reduction
103100204	C	Phys/Chem P&ID Inorganic Waste Neutralization/ Precipitation
103100205	C	Phys/Chem P&ID Inorganic Waste Oxidation/ Reduction
103100206	C	Phys/Chem P&ID Inorganic Waste Sludge Thickening
103100226	C	Phys/Chem P&ID Inorganic Waste Oxidation/ Reduction
103100227	C	Phys/Chem P&ID Inorganic Waste Oxidation/ Reduction
103100231	C	Phys/Chem P&ID Aqueous Organic Wastes Emulsion Breaking
103100232	C	Phys/Chem P&ID Aqueous Organic Wastes Centrifuge
103100235	C	Phys/Chem P&ID Aqueous Organic Wastes Storage
103100271	C	Phys/Chem P&ID Reagent Storage & Feeding System Lime
103100272	C	Phys/Chem P&ID Reagent Storage & Feeding System Caustic
103100273	C	Phys/Chem P&ID Reagent Storage & Feeding System Ferric Chloride Storage

Drawing No.	Revision	Title
103100274	C	Phys/Chem P&ID Reagent Storage & Feeding System Sodium Hydrosulphide Storage
103100275	C	Phys/Chem P&ID Reagent Storage & Feeding System - Sulphuric Acid
103100276	C	Phys/Chem P&ID Reagent Storage & Feeding System - Polyelectrolyte
103100277	C	Phys/Chem P&ID Reagent Storage & Feeding System Sodium Bisulphite
103100278	C	Phys/Chem P&ID Reagent Storage & Feeding System Sodium Hypochlorite
103100279	C	Phys/Chem P&ID Reagent Storage & Feeding System Additional Reagents
303300213	D	Solidification P&ID Salt/Ash (At Incinerator)
503520211	C	Tank Farm & Tank Storage P&ID Incinerator Tank Farm Aqueous Organic
503520212	C	Tank Farm & Tank Storage P&ID Incinerator Tank Farm Aqueous Organic
503520213	C	Tank Farm & Tank Storage P&ID Incinerator Tank Farm Aqueous Organic
503520214	C	Tank Farm & Tank Storage P&ID Incinerator Tank Farm Aqueous Organic
503520215	C	Tank Farm & Tank Storage P&ID Incinerator Tank Farm Waste Solvent
503520216	C	Tank Farm & Tank Storage P&ID Incinerator Tank Farm Organic Sludge
503520217	C	Tank Farm & Tank Storage P&ID Incinerator Tank Farm Waste Oil
503520224	C	Tank Farm & Tank Storage P&ID Incinerator Tank Farm Segregated Storage
503520225	C	Tank Farm & Tank Storage P&ID Phys/Chem Tank Storage Neutral/Alkaline
503520226	C	Tank Farm & Tank Storage P&ID Phys/Chem Tank Storage Acidic - Inorganic

Drawing No.	Revision	Title
503520227	C	Tank Farm & Tank Storage P&ID Phys/Chem Tank Storage Acidic - Inorganic
503520228	C	Tank Farm & Tank Storage P&ID Incinerator Tank Farm Organic Sludge
503520229	C	Tank Farm & Tank Storage P&ID Incinerator Tank Farm Organic Sludge
503520230	C	Tank Farm & Tank Storage P&ID Incinerator Tank Farm Segregated Storage
503520233	C	Tank Farm & Tank Storage P&ID Incinerator Tank Farm Waste Blending Liquids
503520234	C	Tank Farm & Tank Storage P&ID Incinerator Tank Farm Blending Sludges
503520235	C	Tank Farm & Tank Storage P&ID Phys/Chem Tank Storage Neutral/Alkaline
503520236	C	Tank Farm & Tank Storage P&ID Phys/Chem Tank Storage Neutral/Alkaline
503520237	C	Tank Farm & Tank Storage P&ID Phys/Chem Tank Storage Aqueous Organic
503520239	C	Tank Farm & Tank Storage P&ID Incinerator Tank Farm Halogenated Waste
503520241	C	Tank Farm & Tank Storage P&ID Incinerator Tank Farm Halogenated Waste
503520242	C	Tank Farm & Tank Storage P&ID Incinerator Tank Farm Waste Oil
503520244	C	Tank Farm & Tank Storage P&ID Phys/Chem Tank Storage Acidic - Inorganic
503520246	C	Tank Farm & Tank Storage P&ID Phys/Chem Tank Storage Neutral/Alkaline - Inorganic
503520248	C	Tank Farm & Tank Storage P&ID Phys/Chem Tank Storage Acidic - Inorganic
503530201	D	Organic Waste P&ID Bulk Waste Unloading Stations 1 to 4
503530202	D	Inorganic Waste P&ID Bulk Waste Unloading Stations 5 to 9

Drawing No.	Revision	Title
503530204	D	Organic Waste P&ID Bulk Waste Unloading Station Type "A"
503530205	D	Organic Waste P&ID Bulk Waste Unloading Station Type "B"
503530206	D	Inorganic Waste P&ID Bulk Waste Unloading Station Type "C"
503530251	D	Tank Truck Washing Facility P&ID Organic Wastes
503530252	D	Tank Truck Washing Facility P&ID Inorganic Wastes

Von Roll - Incinerator Plant Process Flow Diagrams and P&IDs

Drawing No.	Revision	Title
D906	E	Incineration System Piping and Instrumentation Diagram
D906	E	Incineration System Piping and Instrumentation Diagram
D920	D	Feed System Piping and Instrumentation Diagram Hydraulic System
D922	D	Feed System Piping and Instrumentation Diagram Front Wall Cooling System
D923	A	Feed System Piping and Instrumentation Diagram Special Organic Waste Feed
D950	D	Incineration System Piping and Instrumentation Diagram Boiler Drum
D962	D	Residue Handling System Piping and Instrumentation Diagram Flue Gas Cleaning Ash Handling System
D961	D	Residue Handling System Piping and Instrumentation Diagram Boiler Ash Handling System
D971	D	Flue Gas Cleaning System Piping and Instrumentation Diagram
D971	D	Flue Gas Cleaning System Piping and Instrumentation Diagram
D971	D	Flue Gas Cleaning System Piping and Instrumentation Diagram No Liquid Effluent
D971	D	Flue Gas Cleaning System Piping and Instrumentation Diagram
D972	D	Flue Gas Cleaning System Piping and Instrumentation Diagram Caustic Soda Station
D973	D	Flue Gas Cleaning System Piping and Instrumentation Diagram Lime Slurry Station
D980	D	Incineration System Piping and Instrumentation Diagram Service Water and Treated Water Systems

Drawing No.	Revision	Title
D991	D	Burner and Lance System Piping and Instrumentation Diagram
D991	D	Burner and Lance System Piping and Instrumentation Diagram
D991	D	Burner and Lance System Piping and Instrumentation Diagram
D991	D	Burner and Lance System Piping and Instrumentation Diagram
D991	D	Burner and Lance System Piping and Instrumentation Diagram
D991	D	Burner and Lance System Piping and Instrumentation Diagram
D991	D	Burner and Lance System Piping and Instrumentation Diagram
D901	E	Incineration System Case A Process Flow Diagram
D901	E	Incineration System Case A Process Flow Diagram
D903	E	Incineration System Case C Process Flow Diagram
D903	E	Incineration System Case C Process Flow Diagram
D990	E	Burners and Lances Process Flow Diagram
D970	C	Scrubber Chemical Preparation System Process Flow Diagram Cases A, B, and C
D921	A	Solid Waste Handling Process Flow Diagram Case A: 22,500 Drums/Year
D921	A	Solid Waste Handling Process Flow Diagram Case B: 55,395 Drums/Year
D911	D	Drum Handling Facility Piping & Instrumentation Diagram Drum Pump-out Station
D910	B	Drum Handling Facility Process Flow Diagram Initial Concept Case A: 22,500 Drums/Year
D910	B	Drum Handling Facility Process Flow Diagram Initial Concept Case B: 55,395 Drums/Year

APPENDIX B

EXAMPLE OF HAZOPS PROCEDURE AND DOCUMENTATION

APPENDIX B

EXAMPLE OF HAZOPS PROCEDURE AND DOCUMENTATION

As an example of the Hazards and Operability Study (HAZOPS) procedure, consider the following case from the HAZOPS of the Incinerator Tank Farm (see Table B-1). The line for the transfer of aqueous organic waste to its storage tank had been selected for examination. The first guide word was "NONE OF" and it was applied to the parameter "Flow" to define the deviation "No Flow". The HAZOPS team identified and listed the several possible causes of "No Flow" and the possible consequences of "No Flow" at that point in the process. Then the protection that was already provided against "No Flow" and the consequences of "No Flow", at that point in the process, were defined. Finally, the HAZOPS team recommended further action such as changes to the design or operating procedures when it was clear to the team that action was needed.

Note that there are several possible causes for the deviation "No Flow"; that the causes may have different consequences; that the protection against the deviation may be different for different causes; and that different actions may be needed, depending upon the cause, consequence, and protection already provided. Also, note that some causes may have several different consequences. Each unique combination of cause, consequence, and protection describes a different accident scenario, and these are identified in the next to last column of the table with letters indicating the facility area (OS refers to the Organic Waste Storage [Incinerator Tank Farm] Area) and a number to distinguish it from other scenarios for the same area.

TABLE B-1. HAZOPS WORKSHEET

Line or Vessel: 4-inch transfer line OL-048-11-E

Design Intention: Transfer of Aqueous Organic Waste (70-90% water, 6-8 pH) from bulk unloading header to aqueous organic storage tank at up to 45 m^3/h, up to 400 kPa, above freezing temperature

Guide Word: NONE OF

Deviation: No Flow

Cause	Consequence	Protection	Sc ID*	Action/Comments
Pump stops	No hazard		OS-1	
Line blocked due to manual valve closed; OR	Toxic vapor release	High pressure interlock AND double mechanical seal	OS-2	Move manual valve to other side of line from drum handling
Automatic block valve closed; OR Line plug	Fire - burns	High pressure interlock AND double mechanical seal AND ignition source control	OS-3	
	Fire - toxic gas	Same as OS-3	OS-4	
	Chemical burns	Same as OS-2	OS-5	
Line break	Toxic vapor release	None	OS-6	Divide up dike area below pipe rack into smaller areas
	Fire - burns	Ignition source control	OS-7	
	Fire - toxic gas	Ignition source control	OS-8	
	Chemical burns	None	OS-9	

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* Scenario Identification Number

Some scenarios identified in the HAZOPS received considerable discussion during the sessions. When the information from these discussions was too extensive to record on the HAZOPS Worksheets, it was documented as a "Scenario Note". Two examples of scenario notes for scenarios from the worksheet shown in Table B-1 are described below. The worksheets and the scenario notes, plus other pertinent information about the facility area being examined, are included in a series of working documents from the HAZOPS sessions.

Scenario: OS-1

Deviation: No flow

Cause: Pump stops

Consequences: No hazard

Protection: None needed

Comments: No flow from tanker to tank. Possible fire if motor burns out; ignition of waste is handled under a different scenario. No hazardous implications.

Scenario: OS-2

Deviation: No flow

Cause: Line blocked

Consequences: Toxic vapor release

Protection: Protection against this consequence will be via high pressure interlock or low flow switch, and a double mechanical pump seal with a high-pressure buffer liquid.

Comments: The line could be blocked by (1) manual valve closed, (2) auto block valve closed, or (3) line plug. The loss of flow while the pump is still running will cause the pump seal to fail.

For failure of the auto block valve, the root cause could be loss of air to valve if pneumatic, control system failure, or failure of the valve itself. It is assumed that this

Comments (Con't)

valve is a fail-closed valve. The occurrence of this failure is estimated at 0.1 per year.

The position of the manual valve is changed about once a week. Similar valves in the vicinity will most likely be manipulated. The position of the valve handle will indicate the position of the valve. The valve will be tagged with its number. The occurrence of inadvertently closing this valve was estimated by the human reliability specialist on the HAZOPS team at 0.05 per year. The dominant cause is a selection error; i.e., an operator is supposed to close another valve but closes this one instead.

The pump is in a dyked area which limits the size of a liquid pool caused by a leak. The governing waste parameters are the volatility and the toxicity of the chemicals.

APPENDIX C

TYPICAL WASTES DEVELOPED FOR CONSEQUENCE ANALYSIS

APPENDIX C

TYPICAL WASTES DEVELOPED FOR CONSEQUENCE ANALYSIS

In order to quantify the consequences of an accident or plant upset which involves a spill of waste or the inadvertent mixing of two mutually reactive wastes, it is necessary to specify the chemical species present and the amounts involved. The OWMC Waste Characterization Data Base (Canviro, 1984) identifies 281 possible chemicals which could be present in the wastes surveyed. In reality, not all of these will be sent to the Ontario Waste Management Corporation (OWMC) Facility, but a large enough number will that it would be a monumental task to analyze all of the accident scenarios identified in the Hazards and Operability Study (HAZOPS) with all of the chemical species that might be present. In an effort to reduce the effort to manageable proportions, it was decided to develop some waste compositions (typical wastes) that would be typical of and thereby represent the actual wastes in the consequence analyses.

Initially, it was thought that a separate typical waste would need to be developed for each operating area of the facility and for each type of accident (see Section 2.1.1.2). It was later decided that developing a typical waste for each of the nine waste categories (see Section 2.2.1.1) would be adequate for all areas of the facility. It was reasoned that wastes arriving at the facility would be either strictly segregated or deliberately blended. The segregated wastes would be much fewer in number and their actual compositions could be used for the analyses.

A typical waste was defined that had all of the constituents present in each actual waste stream chosen to make up the composite. In general, the five waste streams in a given waste category that were expected to be received by the facility in the largest amounts were chosen. If more than five waste streams were needed to equal one-half of the amount of all the wastes expected of that waste category, additional waste streams were included, although no waste stream was used that represented less than 2 percent of the total amount of that category. The constituents of the chosen waste streams are present in the typical waste in amounts proportional to their amount in the actual waste stream and the proportion of that waste stream in the typical waste. This is discussed in more detail in Section 2.2.1.2.

Typical wastes, developed in this way, reflect the parameters important to estimating facility risk which depends upon the amount of a chemical species treated over a period of time as well as its hazard characteristics. However, when considering the risk of an individual accident scenario, it is recognized that

- Because of the relatively nonhazardous nature of the majority of the wastes, the typical wastes, as defined, are better suited to spill accident scenarios than to other types of accidents, and

- Some individual waste streams, which perhaps are rarely received at the facility, could be more hazardous than particular typical wastes in some accidents.

Table C-1 defines the typical wastes developed for each waste category in terms of their constituents and the amounts present in each typical waste.

REFERENCE

Canviro, 1984. Market Assessment Program - Survey of 500 Industrial Establishments, Prepared by Canviro Consultants.

TABLE C-1. TYPICAL WASTE COMPOSITIONS

AQUEOUS ORGANIC WASTES	group total = 6873			% = 51.5		
	1	2	3	4	5	Total
Tonnes per year ——>	964	769	755	577	473	3538
Water	99	99	98	97	70	94.58
Ammonium hydroxide	0.5					0.14
Phenol	0.2		2			0.48
Silica, grit, etc.	0.3					0.08
Oil & grease		1		1	2	0.65
Dimethyl terephthalate				2		0.33
Paint & ink pigments					15	2.01
Resins					3	0.40
Solvent (MEK)					10	1.34
						100.00

HALOGENATED WASTES	group total = 1716			% = 50.5		
Revised Dec. 9, 1987	1	2	3	4	5	Total
Tonnes per year ——>	358	206	144	85	73	866
Water		27			11	7.35
Trichloroethylene	30		50		6	21.23
Oil & grease	70		50		11	38.18
Resins		32		4		8.01
Plastics		32				7.62
Methylene chloride		3		8		1.50
Toluene		3		38		4.45
Acetone		3		47		5.34
Pigments				3	22	2.14
Varsol					44	3.69
Tylene					6	0.50
						100.00

TABLE C-1. (Continued)

NON-HALOGENATED SOLVENTS, OILS AND SLUDGES								group total = 10255 tonnes/yr					% = 47.9
Revised Nov. 25, 1987	1	2	3	4	5	6	7	8	9	10	11	12	Total
Tonnes per year ——>	904	770	513	412	362	330	296	281	274	261	261	242	4907
Water	60	65	50		25			11	50		40		33.88
Oil & grease	10	25	50	25	75	85		75				5	28.89
Soaps & surfactants						15	75						5.54
Mineral spirits				25			15			90	30		9.40
Metal chips, grit, etc.	1	10					10						2.36
Pigments				25					50	2	20		6.07
Resins				25						6	10		2.95
Solvents (EtOH, T, X, MEK, etc.)										2		15	0.85
Rubber								7					0.40
Carbon								7					0.40
Sulphur	1												0.18
Organic acids	28												5.16
Polyethylene waxes												80	3.94
													100.00

TABLE C-1. (Continued)

NON-PUMPABLE - ORGANIC	group total = 17806	% = 50.0							
Revised Nov. 25, 1987	1	2	3	4	5	6	7	8	Total
Tonnes per year ——>	1766	1416	1298	1162	1067	917	636	635	8897
Water				50		43	74		16.25
Oil & grease	25			10	10				7.47
Grit, silica, glass	75	50	30		45				32.62
Resins		50	30			30			15.43
Esters						3			0.31
Metals and metal oxides				40	45	2	2		10.97
Aromatic hydrocarbons						2			0.21
Pigments						20			2.06
Paper and cellulose			40					40	8.69
Tar/asphalt								50	3.57
Calcium carbonate							6		0.43
Calcium hydroxide							3	10	0.93
Leather							15		1.07
									100.00

INORGANIC ALKALI/NEUTRAL WASTES	group total = 43093	% = 47.5						
Revised Dec 9, 1987	1	2	3	4	5	6	7	Total
Tonnes per year ——>	10014	4226	1665	1583	1029	1005	966	20488
Water	90	99	86.5	95	90.4	68.5	75	90.22
Calcium hydroxide	10		10	0.5				5.74
Calcium carbonate			1					0.08
Magnesium hydroxide			1					0.08
Caustic					7.7			0.39
Sodium salts						30	0.5	1.50
Silica & inerts			1	3.5				0.35
Silver		0.2						0.04
Copper		0.2						0.04
Organic acids		0.2						0.04
Sulphuric acid		0.2						0.04
Ammonium hydroxide		0.2						0.04
Ammonium chloride							20	0.94
Ferro-alloy			0.5					0.04
Styrene				0.5				0.04
Acrylonitrile				0.5				0.04
Toluene					1.3	1	4	0.30
Phenol					0.6	0.5	0.5	0.08
								100.00

TABLE C-1. (Continued)

INORGANIC ACIDIC WASTES	group total = 19844			% = 51.5		
Revised Nov. 20, 1987	1	2	3	4	5	Total
Tonnes per year ——>	3717	2265	1476	1453	1301	10212
Mineral acids (H2SO4, etc.)	10	1	8	77	40	21.07
Water	89	99	90	23	50	77.00
Heavy metals	1				10	1.64
Ferrous sulphate			2			0.29
						100.00

CYANIDE WASTES	group total = 848			% = 72.1		
Revised Dec. 15, 1987	1	2	3	4	5	Total
Tonnes per year ——>	208	166	146	70	21	611
Water	95	98.6	98	90	89.5	95.93
Cyanide	2	1	1	1	7.5	1.56
Caustic					1.5	0.05
Zinc	2			3		1.02
Cadmium	1					0.34
Copper		0.2	1	3	1.5	0.69
Nickel		0.1				0.03
Tin		0.1		3		0.37
						100.00

TABLE C-1. (Continued)

CHROMATE WASTES	group total = 8277			% = 77.7		
Revised Dec. 15, 1987	1	2	3	4	5	Total
Tonnes per year ——>	2114	1859	1456	677	324	6430
Water	96	99	90	97	95	95.56
Chromate	2	0.3	3	1	0.5	1.55
Sodium chloride	2					0.66
Nickel		0.3			0.5	0.11
Iron		0.4			2	0.22
Zinc			1			0.23
Phosphate			1			0.23
Nitrite/nitrate					2	0.10
Caustic				2		0.21
Oil & grease			5			1.13
						100.00

NON-PUMPABLE - INORGANIC	group total = 31238			% = 60.8		
Revised Dec. 15, 1987	1	2	3	4	5	Total
Tonnes per year ——>	9383	3631	2179	1900	1899	18992
Silica, clay	1	97		50		24.04
Furfural		1				0.19
Formaldehyde		1				0.19
Toluene		1				0.19
Sulphur			30		0.5	3.49
Lead			15			1.72
Copper			20			2.29
Iron			20			2.29
Metals	6			50		7.97
Anhydrides					0.5	0.05
Ammonium nitrate					34	3.40
Ammonium phosphate					34	3.40
Urea					30	3.00
Calcium carbonate	43					21.24
Water	50		15		1	26.52
						100.00

APPENDIX D

ACCIDENT SCENARIO CODING PROCEDURE

APPENDIX D

ACCIDENT SCENARIO CODING PROCEDURE

D-1.0 ACCIDENT SCENARIO CODES

The accident scenarios identified in the Hazards and Operability Study (HAZOPS) sessions of the hazard analysis were coded by the scenario attributes that contribute to and describe the "Initial Accidental Event". The initial accidental event is defined as the initial effect or result of the failures and/or errors associated with the accident scenario. In the scenarios identified in the HAZOPS of the Ontario Waste Management Corporation (OWMC) Treatment Facility, the initial accidental event is often an accidental release of liquid waste material. In other scenarios, the initial accidental event is some other event such as an accidental mixing of incompatible wastes or reagents.

The accident scenario coding procedure was used to group scenarios which have similar characteristics in terms of the nature and magnitude of the initial accidental event. For example, releases of the same class of waste, with the same release rate, duration, maximum pool size, and waste temperature were grouped together for consequence analysis. Appendix D describes the format of the entries in the accident scenario codes.

The accident scenario code does not specify the onsite or offsite consequences of the accident scenarios in terms of health effects or property loss; rather, it specifies the initial conditions for determining the onsite and offsite consequences, including the waste category that is involved. It is then necessary to designate or specify a particular waste composition for the consequence analysis to estimate onsite and offsite health effects attributable to the accident scenarios represented by a particular accident scenario code.

D-2.0 DATA ENTRY FORMAT FOR ACCIDENT SCENARIO CODE

The input to the accident scenario code is determined by a set of attributes. The first attribute, accident type, defines the type of accident being considered. For each of the accident types, additional attributes provide more information on the accident type being considered. Table D-1 lists the identifiers that are used to specify the accident type.

TABLE D-1. ACCIDENT TYPE IDENTIFIERS

Accident Type	Accident Type Identifier
Liquid release	L
Fume release	F
Vapor release	V
Explosion	E
Mixing of chemicals	M
Not applicable	NA
No hazard	NH
Other	O

D-2.1 Liquid Release (L) Accident Scenario Coding

The liquid release category is used when a loss-of-containment accident causes a liquid release. Also, scenarios that may involve a fire or explosion after the release, but where the fire or explosion are not the cause of the release, are included in this category.

This accident type is defined by five attributes:

1. Waste category
2. Total release size (kg)
3. Surface area (m^2)
4. Release duration (min)
5. Temperature of waste.

The format of the accident scenario code for this accident type is L-VV-W-XXX-Y-Z where

L	specifies that this scenario causes a liquid release,
VV	is the waste class identifier,
W	is the total release size identifier,
XXX	is the surface area identifier,
Y	is the release duration identifier, and
Z	is the waste temperature identifier.

The identifiers for each of the attributes of the liquid-release-type accident are described below.

D-2.1.1 Waste Category Identifiers

The waste category attribute is used to identify the general type of waste material in the system at that time. Table D-2 lists the identifiers used for various waste categories.

TABLE D-2. WASTE CATEGORY IDENTIFIERS

Waste Category	Waste Category Identifier
Organic halogenated wastes	HW
Aqueous organic wastes	AO
Organic nonhalogenated solvents, oils and sludges	WS
Organic nonpumpable wastes	ON
Inorganic acidic wastes	AC
Inorganic neutral/alkaline wastes	NA
Cyanide wastes	CY
Chromate wastes	CH
Inorganic nonpumpable wastes	IN
Incinerator fumes	IF
Segregated waste	SW

D-2.1.2 Total Release Size Identifiers

The total release size attribute is used to identify the total amount of waste material that is expected to be released in the scenario. Table D-3 lists the identifiers to be used for total release size.

TABLE D-3. TOTAL RELEASE SIZE OF LIQUID RELEASE IDENTIFIERS

Liquid Total Release Size (m^3)	Liquid (H_2O) Total Release Size (kg)	Total Release Size Identifier
0.1	100	A
0.2	200	B
0.5	500	C
1.0	1,000	D
2.0	2,000	E
5.0	5,000	F
10.0	10,000	G
20.0	20,000	H
50.0	50,000	I
100.0	100,000	J

D-2.1.3 Surface Area Identifiers

The surface area attribute specifies the maximum area of the pool resulting from the release. The input value used is the surface area enclosed within the containment (dikes, berms, building walls, etc.) in square meters. Two other calculation methods were used for specific cases. First, if a relatively small release is spilled into a large area or if the spill was unconfined, the surface area was calculated using an average pool depth of 10 mm. Second, for the pipe rack area, the surface area was taken as 50 m^2 area for each 2.3 m^3 volume of spilled material, based on preliminary design information of the curbed area under the pipe rack (storm drains/sumps every 50 m; volume of 1.44 m^3 per sump, slope of 1 percent).

D-2.1.4 Release Duration Identifiers

The release duration attribute is used to identify the length of time for which the release from containment is expected to occur before being terminated (i.e., by either an operator response or by depletion of released material). Note that a pool may still exist following termination of the release. Table D-4 lists the identifiers to be used for release duration.

TABLE D-4. DURATION OF LIQUID RELEASE IDENTIFIERS

Duration of Release (min)	Duration Identifier
Instantaneous	0
5	1
10	2
30	3
60	4
120	5
1,440	6

D-2.1.5 Temperature Identifiers

The temperature attribute is used to identify whether the temperature of the waste material being released is high (H), medium (M), or ambient (A) temperature.

An example of a Liquid Release Accident Scenario Code is 'L-AO-C-075-2-A', which stands for a liquid release of aqueous organics. The amount released is expected to be about 500 kg over a 10-min period. The maximum pool size is 75 m^2, and the waste is at ambient temperature.

D-2.2 Fume/Vapor (F/V) Release Accident Scenario Coding

The fume release accident type designates a loss-of-containment accident which causes a release of fumes from the Incinerator Plant. The vapor release accident type designates an accidental release of a vapor as a result of inadvertent mixing of reactive chemicals, overheating of a storage tank, or some other accident involving a vapor release as the initial accidental event. The fume release and the vapor release accidents are characterized by the same accident scenario code attributes except for the initials F and V which distinguish the accident type. Scenarios that may involve a fire or explosion after the release, but where the fire or explosion is not the cause of the release, are included in this category.

This accident type is defined by three attributes:

1. Waste category
2. Total release size (kg)
3. Release duration (min)

The format of the accident scenario codes for this type of accident is F-XX-Y-Z or V-XX-Y-Z where

F specifies that this scenario causes a fume release, or

V specifies that this scenario causes a vapor release,

XX is the waste category identifier,

Y is the total release size identifier, and

Z is the release duration identifier.

The identifiers for each of the attributes are described below.

D-2.2.1 Waste Category Identifiers

The waste category attribute is used to identify the general type of waste material in the system at that time. Table D-2 lists the identifiers to be used for various waste categories.

D-2.2.2 Total Release Size Identifiers

The total release size attribute is used to identify the total amount of material that is expected to be released in the scenario. Table D-5 lists the identifiers to be used for total release size.

TABLE D-5. TOTAL RELEASE SIZE IDENTIFIERS FOR FUME/VAPOR RELEASES

Fume or Vapor Total Release Size (kg)	Total Release Size Identifier
1	A
2	B
5	C
10	D
20	E
50	F
100	G
200	H
500	I
1,000	J

D-2.2.3 Release Duration Identifiers

The release duration attribute is used to identify the length of time for which the release from containment is expected to occur before being terminated (i.e., by either an operator response or by depletion of released material). Table D-4 lists the identifiers to be used for release duration.

An example Fume/Vapor Release Accident Scenario Code is 'F-AO-C-2', which means a fume release of aqueous organics. The amount released is expected to be 5 kg over a 10-min period.

D-2.3 Explosion Accident Scenario Coding

The explosion accident scenario code is used when the direct result of a scenario is an explosion. This category is not used when the explosion is a result of a liquid or fume/vapor release. The type of explosion dealt with here would typically be caused by continued pumping to a tank with vent valves closed, incineration of an excessive amount of explosive material, or a lightning strike to a tank. Explosions caused by the mixing of incompatible wastes would not be considered here. Releases would consist of the waste material(s) and any reaction products. Additional effects could result from the high-energy debris expelled from the explosion.

This category is defined by five attributes:

1. Waste category
2. Plant location
3. Containment volume (m^3)
4. Containment burst pressure (kPa)
5. Explosion type.

The format of the accident scenario codes for this accident type is E-VV-WW-X-YYY-Z where

E specifies that this scenario is an explosion,

VV is the waste class identifier,

WW is the plant location identifier,

X is the containment volume identifier,

YYY is the containment burst pressure, and

Z is the explosion type identifier.

The identifiers for each of the attributes are described below.

D-2.3.1 Waste Category Identifiers

The waste category attribute is used to identify the general type of waste material in the system at that time. Table D-2 lists the identifiers to be used for various waste categories.

D-2.3.2 Plant Location Identifiers

The plant location attribute is used to identify the section of the plant where the explosion occurs. This identifier is the same as the first two characters of the accident scenario identifier, e.g., OS for an accident scenario in the Organic Storage Area (Incinerator Tank Farm) of the OWMC Facility.

D-2.3.3 Containment Volume Identifiers

The containment volume attribute specifies the size of the containment. Table D-6 lists the identifiers used for containment size.

TABLE D-6. CONTAINMENT VOLUME IDENTIFIERS

Volume of Tank or Vessel (m3)	Containment Volume Identifier
0.1	A
0.2	B
0.5	C
1	D
2	E
5	F
10	G
20	H
50	I
100	J

D-2.3.4 Containment Burst Pressure Identifiers

The containment burst pressure attribute specifies the burst pressure of the containment. The input value used is the actual containment burst pressure in kPa.

D-2.3.5 Explosion Type Identifiers

The explosion type attribute identifies the type of explosion. Table D-7 lists the identifiers used for type of explosion. The mechanical type of explosion typically refers to those explosions caused by pumping to a tank without venting the tank. A vapor deflagration type of explosion typically refers to those explosions caused by a loss of tank-blanketing gas and the presence of an ignition source. A detonation type of explosion typically refers to those explosions caused the incineration of unexpected wastes such as dynamite.

TABLE D-7. EXPLOSION TYPE IDENTIFIERS

Explosion Type	Explosion Type Identifier
Mechanical	M
Vapor deflagration	V
Detonation	D

D-2.4 Mixing of Chemicals Accident Scenario Coding

The mixing of chemicals category is used when potentially incompatible wastes or wastes and reagents are inadvertently mixed. This mixing can occur because pipes, tanks, or vessels were not properly flushed or drained, or because they were already in use and the wrong waste or reagent was added or was already present when the correct waste or reagent was added.

This accident type is defined by several attributes. The number of attributes and the format of the accident scenario codes varies with the type of containment. The general attributes are

1. Containment type
2. Waste categories (or reagent) added
3. Flow rates
4. Waste category present
5. Reason present
6. Volume of containment.

D-2.4.1 Containment Type Identifiers

The first attribute, containment type, specifies whether the mixing occurs in a tank or vessel, or in a pipe. Table D-8 lists the identifiers to be used for the containment type.

TABLE D-8. CONTAINMENT TYPE IDENTIFIERS

Containment Type	Containment Type Identifier
Tank or vessel	T
Pipe	P

D-2.5 Mixing of Chemicals - Tank or Vessel (M-T) Accident Scenario Coding

The format of the accident scenario code for this type of accident is M-T-VV-WW-XX-Y-Z where

M specifies that this scenario is caused by mixing incompatible wastes,

T specifies that the containment is a tank or vessel,

VV is the waste category identifier for the waste being added to containment, WW is the flow rate identifier,

XX is the waste category identifier for the waste already present in containment,

Y is the containment volume identifier, and

Z is the reason identifier.

The identifiers for each of the attributes are described below.

D-2.5.1 Waste Category Identifiers

The waste category attributes are used to identify the general types of waste materials being inadvertently mixed. Table D-2 lists the identifiers to be used for various waste classes.

A chemical reagent might be one of the chemicals being inadvertently mixed. Two designations for reagents have been used in the accident scenario coding, RE and RT, substituting for the waste category in the accident scenario code when a reagent is expected to be involved.

D-2.5.2 Flow Rate Identifiers

The flow rate attribute specifies the flow rate of the waste class being added to containment. The input value used is the actual flow rate of the waste.

D-2.5.3 Containment Volume Identifiers

The containment volume attribute specifies the size of the containment. Table D-6 lists the identifiers used for containment size.

D-2.5.4 Reason Present Identifiers

The reason present attribute specifies why waste is still in the containment. Table D-9 lists the identifiers used for reason present.

TABLE D-9. REASON PRESENT IN TANK/VESSEL IDENTIFIERS

Reason Present	Reason Present Identifier
Tank/vessel not flushed	F
Tank/vessel in use	I

D-2.6 Mixing of Chemicals - Pipes (M-P) Accident Scenrario Codes

The attributes used if the mixing occurs in a pipe depends on why the waste is still in the pipe. Table D-10 lists the identifiers used for reason present.

TABLE D-10. REASON PRESENT IN PIPE IDENTIFIERS

Reason Present	Reason Present Identifier
Pipe not flushed	F
Pipe not drained	D
Pipe in Use	I

D-2.7 Mixing of Chemicals - Pipe - Not Flushed or Drained (M-P) Accident Scenario Coding

The format of the accident scenario codes for this type of accident is M-P-V-WW-XX-Y-Z where

M	specifies that this scenario is caused by mixing incompatible wastes,
P	specifies that the containment is a pipe,
V	specifies the reason present (from Table D-11),
WW	is the waste class identifier for the waste being added to containment,
XX	is the waste class identifier for the waste already present in containment,

Y is the pipe diameter identifier, and
Z is the pipe length identifier.

The identifiers for each of the attributes are described below.

D-2.7.1 Waste Category Identifiers

The waste category attributes are used to identify the general types of materials being mixed. Table D-2 lists the identifiers used for various waste categories.

A chemical reagent might be one of the chemicals being inadvertently mixed. Two designations for reagents have been used in the accident scenario coding, RE and RT, substituting for the waste category in the accident scenario code when a reagent is expected to be involved.

D-2.7.2 Pipe Diameter and Pipe Length Identifiers

The pipe diameter and pipe length attributes are used to determine the amount of material already present. The input values are the actual pipe length in meters (m) and diameter in centimeters (cm).

D-2.8 Mixing of Chemicals - Pipe - In Use (M-P-I) Accident Scenario Coding

The format of the accident scenario codes for this type of accident is M-P-I-WW-XX-YY-ZZ where

M specifies that this scenario is caused by mixing incompatible wastes,
P specifies that the containment is a pipe,
I specifies the reason present is that the pipe is in use,
WW is the waste class identifier for the first waste being added to containment,
XX is the flow rate identifier for the first waste being added,
YY is the waste class identifier for the second waste being added to containment, and

ZZ is the flow rate identifier for the second waste being added.

The identifiers for each of the attributes are described below.

D-2.8.1 Waste Category Identifiers

The waste category attributes are used to identify the general types of materials being mixed. Table D-2 lists the identifiers to be used for various waste categories.

A chemical reagent might be one of the chemicals being inadvertently mixed. Two designations for reagents have been used in the accident scenario coding, RE and RT, substituting for the waste category in the accident scenario code when a reagent is expected to be involved.

D-2.8.2 Flow Rate Identifiers

The flow rate attributes specify the flow rates of the waste classes being added to containment. The input values used are the actual flow rates of the wastes in cubic meters per hour.

D-2.9 Not Applicable (NA) Accident Scenario Coding

The not applicable category is used when the initial accidental event of a scenario occurs in another plant section. These scenarios are marked with an asterisk (*). An example of a scenario where this happens is as follows. If a valve in the plant section being analyzed fails, it may cause the pump seal in a pump upstream from the valve to fail. If the pump seal does fail, there may be a liquid release in the plant section containing the pump. If the pump is in a different section of the plant, the release should be evaluated in that plant section. Therefore, the scenario involving the valve failure was cross-referenced to the other plant section.

D-2.10 No Hazard (NH) Accident Scenario Coding

The no hazard category is used when the consequences of an accident scenario are recognized in the HAZOPS session as presenting no hazard or no consequences and it is so recorded on the HAZOPS Worksheet.

D-2.11 Other (O) Accident Scenario Coding

The other accident scenario coding was used for accidents that did not fit any of the previous categories. The scenarios in this category were not grouped together for input to the consequence analysis unless a significant number were found to be similiar. The remainder were analyzed individually.

The format of the accident scenario codes for this accident type is O-XXXX, where the O stands for other category, and XXXX is the accident scenario number.

APPENDIX E

CONSEQUENCE ANALYSIS METHODS/PROCEDURES

APPENDIX E

CONSEQUENCE ANALYSIS METHODS/PROCEDURES

The consequence analysis was a screening analysis to identify the accident scenarios that might have significant consequences. A quantitative analysis was performed, but conservative values for many parameters were used to simplify the analysis. This meant that the results were conservative; i.e., the accident scenarios which clearly do not have any significant consequences and hence do not present an important risk were screened out from further consideration; the remaining accident scenarios were analyzed for likelihood of occurrence and onsite/offsite risk. The methods/procedures used for the consequence analyses, including assumptions and sources, are described in the following sections.

E-1.0 MIXING OF INCOMPATIBLE CHEMICALS

Accidental mixing of incompatible wastes, of wastes with the wrong reagents, and of incompatible reagents could potentially occur in many of the unloading, storage, or reaction tanks or in the pipes connecting them. Each scenario or group of scenarios identified in the Hazards and Operability Study (HAZOPS) having the same accident scenario code were analyzed individually, taking into consideration the characteristics of the system where the mixing might occur and all possible combinations of the chemicals involved. Two examples of the analyses done to estimate the results of inadvertent mixing of chemicals are presented here to illustrate the approach that was used.

Example No. 1

Accident Scenario Code: M-T-AC-45-WS-J-I

Scenario(s): OS-74D

Accident Description: Inorganic acidic waste is 2accidentally unloaded into a tank already containing organic non-halogenated solvents/sludges

Compositions of Wastes/Reagents Involved:

Typical Nonhalogenated Waste	%
Water	33.88
Oil & grease	28.98
Soaps & surfactants	5.54
Mineral spirits	9.40
Metal chips, grit, etc.	2.36
Pigments	6.07
Resins	2.95
Solvents (Etoh, T, X, MEK, etc.)	0.85
Rubber	0.40
Carbon	0.40
Sulphur	0.18
Organic acids	5.16
Polyethylene waxes	3.94

Typical Acidic Waste	%
Mineral acids (H_2SO_4, etc.)	21.07
Water	77.00
Heavy metals	1.64
Ferrous sulphate	0.29

Method of Analysis:

Using EPA-600/2-80-076 (EPA) and NFPA 491m (NFPA, 1986) as reference material, each component pair combination was examined for potential incompatibility which would result in the generation of a toxic gas/vapor. In addition, the concentrations present in each of the individual streams making up the typical wastes were considered.

Results of Analysis:

(1) Acidic waste streams contain strong sulphuric acid (could be up to 70 percent for the individual waste stream). Mixing such streams with the (free) water contained in the other waste will result in some heating effects which could cause some vaporization of low-boiling solvents. In this case the heating effect of diluting 70 percent sulphuric acid was found to be of little consequence.

(2) "Metal chips" may react with sulphuric acid to generate some hydrogen. In this case no significant reactions which could result in the release of toxic gas/vapor would occur between any of the constituents of this pair of typical wastes.

Example No. 2

Accident Scenario Code: M-T-AC-12-CY-H-I

Scenario(s): IR-73.1 and IR-75.1

Accident Description: A drum full of acidic waste is unloaded into an unloading tank which already contains some cyanide waste.

Compositions of Wastes/Reagents Involved:

Typical Inorganic Acidic Waste	%	Typical Cyanide Waste	%
Mineral acids (H_2SO_4, etc.)	21.07	Water	95.93
Water	77.00	Cyanide	1.56
Heavy metals	1.64	Caustic	0.05
Ferrous sulphate	0.29	Zinc	1.02
		Cadmium	0.34
		Copper	0.69
		Nickel	0.03
		Tin	0.37

Method of Analysis:

Using EPA-600/2-80-076 (EPA) and NFPA 491m (NFPA, 1986) as reference material, each component pair combination was examined for potential incompatibility which could result in the generation of a toxic gas/vapor. Where potential incompatibility problems were found, the concentrations present in each of the individual streams making up the typical wastes were considered and a quantitative analysis of the reaction to estimate the amount of gas/vapor generated was made where necessary.

Results of Analysis:

Some acid will be consumed by neutralization of the caustic present; the remainder will react with uncomplexed cyanide to form HCN.

It is assumed that the drum contains 200 L of 21.07 wt.% H_2SO_4, and the unloading basin contains 10 m^3 of cyanide waste. Twenty-nine L of acidic waste are consumed by neutralizing the caustic. The remaining 171 L of acid waste will react to form 20 kg of HCN. Since HCN dissolves well in the aqueous solution, it will not vaporize immediately after it is formed for the concentration level indicated above. Instead, it will dissolve in the solution, then migrate across the liquid-gas interface. According to laboratory tests done by Zenon Environmental Corp., the release rate under this condition is proportional to the free cyanide concentration and the liquid-gas interface area, and, at 15,600 ppm cyanide ion concentration, the release rate will be approximately 900 mg of HCN/m^2 per minute. The liquid-gas area is 3 m by 2.5 m. The HCN release rate is estimated to be

$$(900 \text{ mg/m}^2 \text{ min}) \times (3 \text{ m} \times 2.5 \text{ m}) = 6{,}750 \text{ mg/min}$$
$$\text{or } 112.5 \text{ mg/s}$$

E-2.0 CONTAINMENT RUPTURE

The blast effects of an explosion (overpressure, flying debris, structural damage) were evaluated simultaneously based on a TNT equivalency of the energy release upon rupture of a line or vessel. The following equation (Bodurtha, 1980) was used to calculate the TNT equivalent:

$$W = \frac{A \times Pb \times V}{k-1}\left(1 - [Pa/(A \times Pb)]^{(k-1)/k}\right)$$

where

W is the blast energy in kg TNT

Pb is the static burst pressure of the containment in kpaa

A is a "strain factor" to convert the static burst pressure to the dynamic burst pressure (= 1.25 for pressure rise rates of 2,000 to 10,000 psi/s)

V is the vapor volume in m^3

k is the ratio of the vapor specific heats (= 1.25 for triatoms such as carbon monoxide and water vapor)

Pa is the pressure of the surrounding air in kPa(abs).

E-3.0 LIQUID RELEASE AND EVAPORATION (WITHOUT POOL FIRES)

The evaporation of liquid releases was assumed to take place from a pool formed on the ground. The following equation was used to calculate the emission rate of the vapor of concern as a result of evaporation (McKay, 1973):

$$ER = \frac{F \times Kg \times A \times VP \times MW}{0.06236 \times T} \quad (g/s)$$

where

ER = emission rate (g/s)
F = fraction of chemical in question in waste
Kg = mass transfer coefficient (m/s)
A = area (m^2)
VP = vapor pressure at 20 to 25°C as mm Hg
MW = molecular weight
T = temperature (°K)

The accident scenario code specifies the area of the pool and the ambient temperature. A typical waste was identified for each of waste categories in the accident scenario codes. A list of the constituents of each typical waste also provided information on the fraction of each chemical constituent of that waste. However, not all of the constituents of each typical waste are considered to be toxic. ENVIRON provided acute toxicity data for specific toxic chemicals in terms of reversible health effects, irreversible health effects, and lethal health effects. ORTECH International (formerly Ontario Research Foundation) then calculated an emission rate due to evaporation for the chemicals within the typical waste for which toxicity was a concern.

E-4.0 LIQUID RELEASE FOLLOWED BY POOL FIRE AND FORMATION OF TOXIC COMBUSTION PRODUCTS

Formation of toxic combustion products can occur when chemicals containing nitrogen, sulfur, or halogens (i.e., chlorine, fluorine, bromine) are burned. Complete combustion of these chemicals will result in formation of nitrogen oxides (NO_x), sulfur dioxide (SO_2), hydrogen chloride (HCl), hydrogen fluoride (HF), or hydrogen bromide (HBr). Other toxic chemicals such as phosgene, acrolein, hydrogen cyanide, soot, and carbon monoxide may also be evolved in pool fires as a result of incomplete combustion.

E-4.1 Formation of Toxic Combustion Products

E-4.1.1 Phosgene

Combustion of chlorinated chemicals results in the formation of hydrogen chloride gas (HCl) as a toxic product of combustion and, for some chemicals, phosgene ($COCl_2$) as a toxic product of incomplete combustion. The potential for phosgene formation during combustion of chlorinated compounds was evaluated as follows. Stull (Stull, 1971) indicates that both carbon monoxide (CO) and free chlorine must be present to form phosgene during combustion of vinyl chloride. The highest carbon monoxide concentration is found under oxygen-deficient conditions which also yield high hydrogen concentrations. Thus, under lean oxygen conditions required to form carbon monoxide, the free chlorine is consumed to form HCl. Under oxygen-rich conditions conducive to formation of free chlorine, CO is converted to carbon dioxide. Experiments were described by Stull where up to 20 to 40 ppm $COCl_2$ can be produced from combustion of vinyl chloride under controlled laboratory conditions which included premixing vinyl chloride with oxygen prior to combustion. Without premixing, no detectable amounts of $COCl_2$ were produced.

O'Mara (O'Mara, 1971) reported the following equation to determine the potential for phosgene formation during combustion of chlorinated hydrocarbons:

$$\alpha = \frac{\text{number of chlorine atoms} - \text{number of hydrogen atoms}}{\text{number of carbon atoms}}$$

When α is ≥ 0.4, phosgene can form during combustion. The potential for phosgene formation for several chlorinated compounds is given in Table E-1.

Sjoberg (Sjoberg, 1952) studied the decomposition of chlorinated hydrocarbons in contact with a flame. A summary of the results, shown in Table E-2, are in agreement with O'Mara's correlation. O'Mara's correlation and the data in Table E-1 were used to estimate phosgene formation during pool fires involving chlorinated hydrocarbons.

TABLE E-1. POTENTIAL FOR PHOSGENE FORMATION DURING COMBUSTION OF CHLORINATED HYDROCARBONS

Chemical	# Chlorine Atoms	# Hydrogen Atoms	# Carbon Atoms	α^*	Phosgene Formed
Trichloroethane	3	3	2	0	No
Carbon tetrachloride	4	0	1	4	Yes
Chloroform	3	1	1	2	Yes
Chlorobenzene	1	5	6	-0.7	No
Trichloroethylene	3	1	2	1	Yes
Tetrachloroethylene	4	0	2	2	Yes
Trichlorotrifluoroethylene	3	0	2	1.5	Yes
p-Dichlorobenzene	2	4	6	-0.3	No
Methylene dichloride	2	2	1	0	No

* α = (# chlorine atoms - # hydrogen atoms)/# carbon atoms. Phosgene may be formed during combustion if $\alpha \geq 0.40$ (O'Mara, 1971).

TABLE E-2. PHOSGENE FORMATION FROM COMBUSTION OF CHLORINATED HYDROCARBONS (Sjoberg, 1952)*

Chemical	α**	HCl Formed; mg/g Chemical Combusted	Phosgene Formed; mg/g Chemical Combusted	Wt.% of Combusted Chemical Forming Phosgene
Carbon tetrachloride	4	199	8.3	0.8
Chloroform	2	138	6.0	0.6
Trichloroethylene	1	266	1.0	0.1
Tetrachloroethylene	2	238	7.0	0.7
Dichloroethane	-1	240	0.0	0.0
Tetrachloroethane	1	326	2.5	0.3
Pentachloroethane	2	332	2.0	0.2

* Averaged results are reported.

** α = (# chlorine atoms - # hydrogen atoms)/# carbon atoms. Phosgene may be formed during combustion if $\alpha \geq 0.40$ (O'Mara, 1971).

E-4.1.2 Acrolein

Acrolein was identified by Morikawa (Morikawa, 1984) as a constituent in the combustion of hydrocarbons (e.g., hexane) and alcohols (e.g., n-propyl alcohol). Acrolein was shown to be formed at relatively low temperatures (i.e., 650°C or below -- generally nonflaming conditions). At higher temperatures acrolein is unstable and/or less readily formed. In an unconfined hydrocarbon pool fire, acrolein formation is expected to be insignificant because of the high temperatures within the flame envelope.

E-4.1.3 Hydrogen Cyanide

Hydrogen cyanide was shown by Morikawa (Morikawa, 1978) to be formed when any nitrogen containing organic material is heated over 600°C in an oxygen-lean atmosphere. Because pool fires will be unconfined with excess oxygen at the boundaries of the flame envelope, the formation of significant quantities of HCN is not expected.

E-4.1.4 Carbon Monoxide and Soot

Carbon monoxide and soot may also be evolved in pool fires. However, carbon monoxide and soot were not considered in this analysis because carbon monoxide and soot formation are not peculiar to chemical fires but are common combustion products when any organic (e.g., wood, paper, etc.) is burned.

E-4.2 Flammability and Toxic Combustion Product Formation Characteristics of the Typical Wastes

The chemical constituents of each typical waste can be placed in the following groups:

- Flammable liquids that do not contain sulfur, nitrogen, halogens, etc.
- Flammable liquids or solids containing sulfur, halogen, nitrogen, etc. (i.e., chemicals which form toxic combustion products),
- Combustible solids, and
- Water/Inerts (e.g., pigments, dirt, other noncombustible solids).

E-4.2.1 Typical Organic Halogenated Solvents

The typical organic halogenated solvent has the following composition:

- Flammable/combustible liquids including oil/grease, toluene, acetone, varsol and xylene = 52.16 wt. percent,
- Halogenated liquids including trichloroethylene and methylene chloride = 22.73 wt. percent,
- Combustible solids including resins and plastics = 15.63 wt. percent, and
- Water/inerts including water and pigments = 9.49 wt. percent.

All components of this typical waste, other than water and the inerts, are flammable or combustible. For example, trichloroethylene and methylene chloride are flammable when the gas phase concentrations are within the flammability limits of 12 to 40 volume percent and 15.9 to 19.1 volume percent, respectively (Kuchta, 1985). Trichloroethylene has a flash point of 32°C, (Kuchta, 1985). The halogenated chemicals represent the toxic combustion product hazard for this waste category. Although some resins and plastics can generate toxic combustion products, the industrial source of the predominant plastic/resin in the typical waste is from a manufacturer of fiberglass-reinforced plastic storage tanks. Typical resins used in reinforced plastics include phenolic, polyester, epoxy, or silicone resins which should not form toxic combustion products (other than soot and carbon monoxide) when burned in the open air. As such, the flammable solids were not included in the fire analyses for halogenated wastes. It is important to note that, because phosgene formation is not anticipated when methylene chloride is burned, it was conservatively assumed for the fire analyses that the halogenated liquid is composed entirely of trichloroethylene (the methylene chloride was counted as trichloroethylene) which can form phosgene during combustion.

E-4.2.2 Typical Aqueous Organic Waste

The typical aqueous organic Waste composition is as follows:

- Flammable/combustible liquids including oil, grease and methyl ethyl ketone = 1.99 wt. percent,
- Combustible solids including phenol, dimethyl terephthalate, and resins = 1.21 wt. percent, and
- Water/inerts including water, ammonium hydroxide, grit, and pigments = 96.81 wt. percent.

A waste with the above composition may be flammable if the low-density organics such as oil and grease form a layer on top of the water. Methyl ethyl ketone, which could be in either the oil or aqueous layer (soluble in water), was conservatively assumed to be in the flammable oil layer. The combustible solids are either soluble in water (phenol) or denser than water and as such should not be involved in the fire.

Neither oil, grease, nor methyl ethyl ketone would generate significant quantities of toxic combustion products in an open fire.

Ammonium hydroxide may decompose in a fire evolving NO_x fumes. However, because it is present in a low concentration in the typical waste (0.14 wt. percent) and is soluble in water, minimal, if any, quantities of NO_x would be generated during a fire. Thus, the typical aqueous organic waste may be flammable but does not represent a significant hazard in terms of toxic combustion products.

E-4.2.3 Typical Organic Nonpumpable Waste

The typical organic nonpumpable waste composition is as follows:

- Flammable/combustible liquids including oil, grease, esters, and aromatic hydrocarbons = 7.99 wt. percent,
- Resins possibly containing halogens, sulfur, or nitrogen = 15.43 wt. percent,
- Combustible solids including tar, asphalt, paper, cellulose, and leather = 13.33 wt. percent, and
- Water/inerts including water, metals, grit, and calcium salts = 63.26 wt. percent.

A waste with the above composition is flammable -- especially if the mixture is nonuniform with the flammable materials on top of the water/inerts.

The industrial source for the resins contained in this waste indicates that toxic combustion products may be formed because chlorinated, nitrogen-containing, or sulfur-containing resins may be present. It was conservatively assumed that the resin is polyvinyl chloride (PVC). Although PVC is self-extinguishing, it will burn in the presence of an external flame. Combustion of PVC forms hydrogen chloride (15.5 wt. percent of the PVC burned) and phosgene (0.0043 wt. percent of the PVC burned) (Wagner, 1972).

E-4.2.4 Typical Organic Nonhalogenated Solvent, Oil, and Sludge Waste

The typical organic nonhalogenated solvent, oil, and sludge waste composition is as follows:

- Flammable/combustible liquids including oil, grease, mineral spirits, and solvents = 39.14 wt. percent,

- Sulfur = 0.18 wt. percent,
- Combustible solids including soap, resins, rubber, carbon, organic acids (e.g., succinic and glutaric acid), and polyethylene waxes = 18.39 wt. percent, and
- Water/inerts including water, metal chips, and pigments = 42.31 wt. percent.

A waste with the composition given above would have a flammable layer on top of an aqueous layer. The flammable layer would consist of the flammable/combustible liquids, sulfur (assumed to be part of the oil), soaps, and polyethylene waxes. The aqueous layer would consist of the combustible solids with a density greater than water (i.e., resins, carbon, rubber, and the organic waxes) and the inerts.

The toxic combustion product hazard for this waste would be SO_x formed from combustion of the sulfur. Stoichiometric conversion of the sulfur to SO_2 was assumed for this analysis.

E-4.2.5 Typical Inorganic Acidic Waste

The typical inorganic acidic waste composition is as follows:

- Water/inerts including mineral acids such as sulfuric acid, heavy metals, and ferrous sulfate = 100 wt. percent.

This waste is not flammable.

E-4.2.6 Typical Inorganic Alkali/Neutral Waste

The typical inorganic alkali/neutral waste composition is as follows:

- Flammable/combustible liquids including toluene, phenol, and styrene = 0.39 wt. percent,
- Acrylonitrile = 0.04 wt. percent,
- Water/inerts including mineral acids such as sulfuric acid, heavy metals, sodium salts, calcium salts, ammonium salts, etc., = 99.57 wt. percent.

This mixture was conservatively assumed to be flammable/combustible with the flammable liquids and acrylonitrile (solubility of about 8 wt. percent in water) forming a layer on top of the aqueous layer. This would be similar to an oil slick fire on water. The toxic combustion product hazard is NO_x from combustion of acrylonitrile. It was assumed that 50 weight percent of the NO_x formed is NO with the remainder NO_2. It is important to note that inorganic waste with significant organic content will be pretreated in the aqueous organic system in the plant where it is assumed that all of the organics will be separated from the waste. After the organics are removed, the inorganic phase will not be flammable. As such, fires involving the typical inorganic alkali/neutral wastes were considered in the inorganic unloading, inorganic storage, and aqueous organic system areas, but not in the inorganic treatment area.

E-4.2.7 Typical Inorganic Chromate Waste

The typical inorganic chromate waste composition is as follows:

- Flammable liquids including oil and grease = 1.13 wt. percent,
- Water/inerts including heavy metals, caustic, and various salts = 98.87 wt. percent.

This mixture was conservatively assumed to be flammable with the flammable liquids forming a layer on top of the aqueous layer. However, no significant formation of toxic combustion products is anticipated.

E-4.2.8 Typical Inorganic Cyanide Waste

The typical inorganic cyanide waste composition is as follows:

- Water/inerts including mineral acids such as sulfuric acid, heavy metals, and cyanide salts = 100 wt. percent.

This waste is not flammable.

E-4.2.9 Typical Inorganic Nonpumpable Waste

The typical inorganic nonpumpable waste composition is as follows:

- Flammable/combustible liquids including furfural, formaldehyde, toluene, and organic anhydrides = 0.62 wt. percent,
- Organic sulfur = 0.05 wt. percent,
- Water/inerts including silica, heavy metal sulfides, ammonium nitrate, urea, and various salts = 99.33 wt. percent.

It was conservatively assumed that a waste with the composition given above would have a flammable layer on top of an aqueous layer. Also, it was assumed that furfural and formaldehyde are present in liquid/dissolved form rather than the more probable solid polymer form. It is important to note that four of the five waste streams used to develop the typical inorganic nonpumpable waste are not flammable. The flammable layer would consist of the flammable/combustible liquids and organic sulfur. The toxic combustion product hazard for this waste would be SO_x formed from combustion of the sulfur. Stoichiometric conversion of the sulfur to SO_2 was assumed for this analysis.

E-4.3 Fire Analysis Methods and Assumptions

The assumptions used in the fire analysis calculations are as follows:

- Constant burning rate for nonhalogenated wastes.
- Spill burns to completion or until the flammability limit is reached (assumes no mitigation). It is important to note that all buildings storing or handling flammable materials will have appropriate fire detection/alarm systems and fire protection systems (e.g., sprinklers). External plant areas will be protected by a fire hydrant loop, water monitors, and a foam fire protection system. Successful operation of these protection systems would reduce (i.e., mitigate) but not completely eliminate the consequences of the scenario.
- Ideal solution behavior was assumed for liquid density and vapor/liquid equilibria calculations.

- Although several, but not all, of the accident scenarios in the unloading areas occur in a semi-enclosed area (roof and three walls), it was conservatively assumed that all fires in the inorganic and organic unloading areas occur inside a building. As such, the effective release height for all scenarios was taken to be the elevation of the vent stack. Slightly higher release heights may be possible for releases in the semi-enclosed area, but the building wake effect would tend to keep the combustion products near ground level. Further, it was assumed that the ventilation system remains on during the fire (i.e., sufficient oxygen is available for complete combustion).
- All releases in the inorganic and organic unloading areas are exhausted through a vent line at an elevation of 10 m.

The calculation procedure for organic nonhalogenated wastes is given as follows:

1) Calculate the heat of combustion and liquid density of the flammable liquid phase.

2) Determine the burn rate, surface area, and duration of the fire which matches the accident scenario characteristics. Criteria used to determine the burn rate, surface area, and fire duration for the fire scenarios are given as follows:

2a) Calculate burn rate in kg/min as follows:

$$\text{Burn rate (kg/min)} = \text{burn rate (mm/min)} \times 1\ \text{m} / 1000\ \text{mm} \times \text{fire area (size of curbed area)} (\text{m}^2) \times \text{liquid density} (\text{kg/m}^3)$$

Note: Burn rates (mm/min) for individual chemicals were taken from (USCG, 1984). Where data were unavailable, the following correlation was used (Burgess, 1961):

$$\text{Burn rate (mm/min)} = 0.076 \times \frac{\text{Heat of Combustion}}{\text{Heat of Vaporization}}$$

Three cases were then considered:

2b, Case 1) If the burn rate is greater than or equal to the release rate of the liquid, it was assumed that the burn rate equals the release rate (i.e., the liquid pool surface area will increase until the rate of burning equals the rate of release and stay at that size and burn rate until the release stops). The surface area does not enter the calculations. The duration of the fire is the duration of the spill.

2b, Case 2) If the burn rate is less than the release rate of the liquid and the liquid depth in the curbed area is less than or equal to a 1-cm depth (release size too small to fill entire curbed area to a depth of 1 cm), then a spill surface area based on a 1-cm depth was used for the burn rate calculations (Moorhouse and Carpenter, 1986). The burn rate was calculated by the equation given in (2a) with a spill area calculated based on a pool depth of 1 cm. The duration of the fire was estimated by the following equation:

Fire duration (min) = Spill size (m^3) x Liquid density (kg/m^3)/Burn rate (kg/min).

In this case, the duration of the fire will be longer than the spill time.

2b, Case 3) If the burn rate is less than the release rate of the liquid and the liquid depth in the diked area is greater than a 1-cm depth, then the diked surface area given in the accident scenario code was used in the burn rate calculations. The burn rate and the duration of the fire were calculated by the equations given in (2a) and in (2b, Case 2), respectively. In this case, the duration of the fire will also be longer than the spill time.

3) Calculate combustion product rate of formation as follows:

Rate of formation (kg/min) = burn rate (kg/min) / molecular weight of chemical x molecular weight of combustion product x moles combustion product/moles chemical.

4) For outdoor pool fires, estimate an "effective release height" which, as a result of buoyancy effects (i.e., thermal updraft) is the height from which the combustion products will be dispersed. Brummage (Brummage, 1968) reported the following correlations for plume rise as a result of thermal updraft:

Neutral Atmospheric Conditions:

$$\text{Height} = 4.8 \times Q_h^{0.26} / u^{0.76}$$

Slightly Stable Atmospheric Conditions:

$$\text{Height} = 0.26 \times Q_h^{0.45} / u^{0.63}$$

where

Q_h = heat output (cal/s)

u = wind velocity (m/s)

The heat output was estimated based on the burn rate, fire area (i.e., spill size), and heat of combustion of the flammable/combustible liquid phase.

The calculation procedure for the organic halogenated wastes was similar to that described for organic nonhalogenated wastes except for fires where the burn rate was less than the spill rate. For these cases, the following procedures were used:

1) Develop a vapor/liquid equilibria XY curve which relates the vapor phase composition to the liquid phase composition. A two-component ideal solution system was assumed.

2) Estimate the burn rate, liquid density, and heat of combustion of the composite waste.

3) Using 0.1- minute intervals, perform the following:

   3a) Calculate the vapor phase concentration of each component.

   3b) Calculate the amount burned during the interval by

   Amount burned = burn rate (kg/min) x 0.1 min.

   3c) Calculate the generation rate of hydrogen chloride.

   3d) Calculate the amount of each component remaining in the liquid phase.

   3e) Update the burn rate, liquid density, and heat of combustion of the composite waste.

   3f) Repeat Steps (3a) through (3e) until either the flammability limit is reached or the entire spill is combusted. The flammability limit was given as vapor phase concentration of halogen of 70 weight percent or greater (Larsen, 1974).

4) Calculate an average generation rate of hydrogen chloride and estimate the phosgene generation rate based upon information given in Table E-2.

E-5.0 LIQUID RELEASE WITH FIRES AND BOIL-OFF OF WASTES IN TANKS

Accident scenarios have been identified during the HAZOPS sessions which could lead to release of chemicals which ignite and form confined pool fires within the Ontario Waste Management Corporation (OWMC) Treatment Facility. As part of the consequence analyses, the potential for boil-off of uncombusted vapor from tanks exposed to these pool fires was estimated. Boil-off may occur as a result of a pool fire that either directly heats an adjacent tank by thermal radiation or engulfs a tank in fire. If sufficient heat is applied, volatile chemicals within the tank would be vaporized and released either into the vent system or, if enough pressure developed in the tank, through a relief valve located on the storage tank.

E-5.1 Chemicals Used in the Fire Analyses

The organic chemicals anticipated to be processed at the OWMC Facility are grouped into several waste categories, including:

- Organic halogenated solvents,
- Aqueous organic waste,
- Organic nonhalogenated solvents, oils, and sludges, and
- Organic nonpumpable wastes.

Organic nonpumpable wastes were not evaluated for potential boil-off because they are unlikely to contain liquid which could potentially vaporize and produce toxic gases. Most of these wastes are stored in a pit adjacent to the Incinerator. The other organic wastes are to be stored in the Incinerator Tank Farm.

Typical wastes were identified for the consequence analyses for each of the above categories (see Appendix C). The amounts of flammable materials and water/solids/inerts in each of the typical wastes are given in Table E-3.

TABLE E-3. CONCENTRATIONS OF CHEMICALS IN FLAMMABLE TYPICAL WASTES

Typical Wastes	Chemicals	Concentrations, Wt. %
Organic halogenated	Toluene*	46.82
	Trichloroethylene	21.23
	Methylene chloride	1.50
	Acetone	5.34
	Water	7.35
	Solids/inerts	17.77
Aqueous organic	Methyl ethyl ketone	1.34
	Toluene*	0.65
	Water	98.00
Nonhalogenated solvents, oils, and sludges	Toluene*	29.74
	Methyl ethyl ketone	9.40
	Water	60.86

* Includes oil, grease, mineral spirits, varsol and/or xylene.

E-5.2 Assumptions for Calculations

Assumptions used in the calculations are as follows:

- Spill burns to completion (assumes no mitigation). It is important to note that all buildings in which flammable materials are stored or handled will have appropriate fire detection/alarm systems and fire protection systems (e.g., sprinklers). External plant areas will be protected by a fire hydrant loop, water monitors, and a foam fire protection system. Successful operation of these protection systems would reduce (i.e., mitigate) but not completely eliminate the consequences of the scenario.

- The wind velocity is 5 m/s.

- Both boil-off as a result of a tank engulfed in a fire and as a result of being exposed to thermal radiation from a fire in an adjacent area were considered.

- In the case of a tank engulfed in a fire, it was assumed for all cases other than the halogenated waste storage tanks that one full tank would spill its entire contents into the curbed area, ignite, and heat the other tank(s) within the curbed area. Several iterations were performed in which the amount of waste in each of the nonruptured tanks being heated was varied from 100 percent full down to 10 percent full. This was done to determine the worst case conditions (i.e., highest boil-off rate). Unlike the other plant storage areas, each tank in the halogenated waste storage area is individually curbed. As such, a spill of the entire tank contents would not result in boil-off. It was assumed that a single, initially full halogenated waste storage tank (8-m^3 capacity) would spill between 10 percent and 90 percent of its contents and ignite. The remainder of the liquid waste in the tank would then be subject to boil-off.

- In the case of boil-off resulting from a fire in an adjacent area, it was assumed that one full tank would spill its entire contents into the curbed area and ignite. Tank(s) in adjacent areas would then be subject to boil-off. Several iterations were performed in which the amount of waste in each of the tanks exposed to the fire was varied from 100 percent full down to 10 percent full. This was done to determine the worst case conditions (i.e., highest boil-off rate). Note: Because the halogenated waste storage tank capacity is only 8 m^3, a fire resulting from the spillage of the entire contents of a tank would not represent a significant thermal radiation hazard to adjacent tanks in either the halogenated waste or the organic sludge storage areas. As such, only the boil-off of contents from a halogenated waste tank engulfed in a fire or from a halogenated waste tank exposed to a fire in the organic sludge area were evaluated.

- The following spill sizes were assumed -- 100 m^3 for the waste solvent, waste oil, waste sludge, and aqueous organic waste fires; 60 m^3 for blended liquid and blended sludge fires; 40 m^3 for segregated waste and receiving tank fires; or 0.8 to 7.2 m^3 for halogenated waste fires.

- The vapor/liquid equilibria calculations for the mixtures assumed ideal behavior of the vapor phase and regular solution behavior of the liquid phase.

- Credit is taken for the vent system for safely venting releases from a vent stack (10-m elevation) until the internal tank gauge pressure reaches or exceeds 95 kPag (13.8 psig) at which time part of the vapor would be relieved to the atmosphere through a relief valve. No credit is taken for adsorption of vapors by the carbon filters in the vent system.

- The maximum venting rate was based on boil-off of methylene chloride. This scenario involved a halogenated waste tank initially full with methylene chloride spilling 10 percent of its contents (worst case). Ignition of the spill (low probability for methylene chloride) would result in a fire lasting about 528 seconds assuming a methylene chloride burn rate of 1.3 mm/min (estimated from the heats of vaporization and combustion). The fire would cause the internal pressure to reach 69 kPag (10 psig) at 362 seconds into the fire at which time venting of the tank contents through the vent stack adjacent to the carbon filters would begin and continue for the duration of the fire. The maximum flow rate to the vent system that would prevent opening of the relief valve on the tank would be 0.43 m^3/s @ 10 psig (2.27 kg/s) of methylene chloride vapor. The average flow rate over the course of the fire would be 2.25 kg/s so about 372 total kg of methylene chloride would be released. It was assumed for all calculations involving typical wastes that the vent system is designed to handle these rates.

- The relief valves are sized such that the maximum tank pressure that can be attained is 95 kPag (13.8 psig). This was also assumed to be the relief valve opening pressure.

- The tank supports, vent system, and associated piping are sufficiently fireproofed such that they do not fail when exposed to a fire.

- Thermal radiation levels were estimated using the procedure given in Appendix E-11.

- A distance of 4 m from the flame front was assumed for thermal radiation levels on adjacent tanks.

- Heating rates as a result of a tank engulfed in a fire were estimated using the correlation given by Crozier (Crozier, 1985) for relief rates during fire emergencies. This correlation, given below, is for direct flame impingement on wetted vessel surfaces.

  $$Q = q \times F \times A^{0.82}$$

  where

  Q = heat input to the vessel (BTU/hr),

  q = 34,500 BTU/hr/ft^2

  F = Protection factor (Conservatively assume = 1)

  A = Wetted area of the vessel exposed to direct flame impingement (ft^2)

- Heat is absorbed only by the wetted areas of the tank. A maximum height of 25 ft (7.62 m) was assumed when calculating the wetted area of tanks greater than 25 ft in height (per API-520). The bottoms of the tank were included in the wetted area when the tanks were engulfed in a fire but not when the tanks were heated by adjacent fires.

- The tank heating rate is constant throughout the fire.

E-5.3 Calculation Procedures

The calculation procedure for evaluating boil-off from tanks engulfed in a fire is given as follows:

1) The liquid phase activity coefficients for each of the volatile components in the waste were estimated assuming a regular solution by (Prausnitz, 1969):

   $$RT \ln \gamma_j = v_j (\delta_j - \delta_{avg})$$

   where

   R = gas constant,

   T = temperature (°K),

   γ_j = activity coefficient for component j,

v_j = specific volume of component j (cm^3/gmmole),

δ_j = solubility parameter of component j ($(cal/cm^3)^{1/2}$) taken from a tabulation of solubility parameters for various organic chemicals (Brandup, 1975).

$\delta_{avg} = \Sigma (\Phi_i \delta_i)$ (sum over all components)

where

Φ_i = volume fraction of component i given by:

$$\Phi_i = \frac{x_i v_i}{\Sigma (x_j v_j)}$$

x_i = mole fraction of component i.

2) The partial pressure of each volatile constituent in the waste (including water) was estimated assuming an ambient temperature of 30°C. The following equation was used:

$$p_i = p_i^{sat} x_i \gamma_i$$

where

p_i^{sat} = saturation pressure of component i. The saturation pressure is the vapor pressure of the pure component. Vapor pressure data were taken from Weast (Weast, 1972).

An initial storage tank pressure of 760 mm Hg was assumed. The nitrogen blanket was assumed to make up the difference between the sum of partial pressures of the components and 760 mm Hg.

3) The duration of the fire was estimated using correlations developed to determine thermal radiation hazards to personnel as a result of pool fires (see Appendix E-11).

4) The time required to reach the vent pressure of 69 kPag (10 psig) was estimated by Steps (4a) through (4f).

  4a) The density and specific heat of the waste were estimated and then the sensible heat of the waste in the tank was calculated.

  4b) The wetted area of the storage tanks was calculated.

4c) The rate of heat adsorbed by the tank was calculated using the correlation given by Crozier (Crozier, 1985) and wetted area given in Step (4b).

4d) The total amount of heat adsorbed by the tank and the resultant temperature rise were calculated for a time interval of 1.0 minute into the fire. This involved an iterative calculation in which the temperature in the tank was incrementally increased and a heat balance was performed at each step. The heat balance considered vaporization of volatiles.

4e) The liquid phase activity coefficients, partial pressures, total vapor pressure, specific volumes of each component, and liquid phase composition were recalculated at the new temperature (see Steps 1 and 2).

4f) Steps (4a) through (4e) were repeated until either the fire burns out or until the internal pressure reached 69 kPag. The time interval was decreased from 1.0 minute down to 0.01 minute as the pressure approached 69 kPag.

5) If the fire burned out without the total pressure exceeding 69 kPag, then the solution does not boil and no further calculations were performed. If a pressure of 69 kPag was reached, then vapors would be vented to the atmosphere. The vent rate was calculated by iterating Steps (4a) through (4e) with the rate of vaporization determined by the amount of material vaporized (Step (4d)) divided by the time interval. The composition of the vented vapors was estimated from the partial pressures of the components. This was repeated until either the fire burned out, all the material in the tank vaporized, or a relief pressure of 95 kPag was attained. If the pressure exceeded 69 kPag but did not reach 95 kPag, then an average vent rate and total amount of material vented were calculated to complete the analysis.

6) If the relief pressure of 95 kPag was attained in Step (5), then a fraction of the flow was assumed to be vented through the vent system with the remainder vented through the relief valve.

The calculation procedure for evaluating boil-off from tanks as a result of thermal radiation absorption from adjacent fires is identical to the procedure given above except the thermal radiation levels estimated by the method described in Appendix E-11 were used to determine the heating rates for Step (4c). It was conservatively assumed that the tank was located directly downwind from the fire. Downwind locationss would result in higher thermal radiation levels than crosswind and upwind locations.

E-5.4 Boil-Off Scenarios

The scenarios that were evaluated for boil-off from tanks engulfed in a fire included

- Halogenated waste -- partial spill/boil-off from one tank
- Organic sludge -- one tank spilled/five tanks boil-off
- Waste oil -- one tank spilled/two tanks boil-off
- Waste solvents -- one tank spilled/two tanks boil-off
- Aqueous organic waste -- one tank spilled/six tanks boil-off
- Blended sludge waste -- one tank spilled/one tank boils-off
- Blended liquid waste -- one tank spilled/one tank boils-off
- Receiving tank waste (halogenated, waste solvent, and aqueous organic wastes) -- one tank spilled/three tanks boil-off
- Segregated waste -- one tank spilled/two tanks boil-off

The scenarios that were evaluated for boil-off from tanks exposed to an adjacent fire included

- Boil-off of halogenated waste (three tanks) from an organic sludge area fire
- Boil-off of organic sludge (three tanks) from a waste oil storage area fire
- Boil-off of waste oil (three tanks) from an organic sludge storage area fire
- Boil-off of waste oil (three tanks) from a waste solvent storage area fire
- Boil-off of waste solvents (three tanks) from a waste oil storage area fire
- Boil-off of waste solvents (three tanks) from an aqueous organic storage area fire
- Boil-off of aqueous organics (three tanks) from a waste solvent storage area fire
- Boil-off of aqueous organics (three tanks) from a blended sludge storage area fire

- Boil-off of blended sludge (two tanks) from an aqueous organic storage area fire
- Boil-off of blended liquids (two tanks) from a blended sludge storage area fire
- Boil-off of blended sludge (two tanks) from a blended liquids storage area fire

E-6.0 VAPOR GENERATION AND RELEASE

Mixing of incompatible wastes, of wastes with incompatible reagents, and of incompatible reagents could generate toxic vapor which could not be contained within the system. The basis and assumptions used for estimating the rate of toxic gas release for these mixing scenarios are described below.

The quantity of chemical produced in a given reaction was calculated from the stoichiometry of the system taking into account the volume of the vessel and the quantity of the other reactant being added. Whichever reactant was consumed first determined the quantity of chemical product generated. The chemical reaction was assumed to be instantaneous. Therefore, the rate of chemical product generated will be determined by the addition rate of the reactant.

Since all the gases of concern (SO_2, H_2S, Cl_2, etc.) are fairly soluble in water, it was also necessary to consider the individual solubilities and the quantity of water present at any given time. In some cases, it was found that there was more than sufficient water either present originally, or added with the second reactant, to maintain the reaction product in solution. In these cases, it was assumed that no gas release would occur.

In other cases, it was determined that a considerable time delay would occur before the water present became saturated and a gas release commenced.

It should be noted that no credit has been taken for such time delays; furthermore, once initiated, the flow of the reactant has been assumed to continue until either no further reaction can take place or the vessel in which the reaction is taking place has overflowed. This determines the duration of gas release.

E-7.0 INCINERATOR FUME RELEASE

Accident scenarios involving releases of fumes from the incinerator were not included in the facility risk calculations, due to an inability to quantify both the magnitude of release for various accident scenarios and the composition and toxicity of fumes. However, fume release scenarios were evaluated qualitatively as part of the HAZOPS discussions, and the following conclusions were made:

- As long as the induced draft (ID) fan is in operation and the kiln is operating within its normal pressure range (10-mm H_2O vacuum), any small openings in the kiln/gas cleaning system upstream of the ID fan, such as bad seals or leaking flanges, will draw air into the system and will not result in fume releases.

- The most likely expected cause of fume releases is the introduction of a significant quantity of a highly volatile and flammable waste into the kiln, such as a drum of organic solvent, causing a momentary pressure surge in the kiln and "puff" release of fumes through the kiln seals and front wall chute into the area immediately around the kiln. The duration of such "puffs" is typically 1 to 2 seconds; some risk may be posed to a worker in the immediate area at the time of the "puff", but the magnitude of the release would not be significant with respect to offsite health effects. OWMC procedures will specify the maximum bulk quantity which can be introduced into the kiln at one time and not cause a "puff", such as one-half of a 200-L drum.

- In the case of the "puff" described above, the composition of the "fumes" would be the composition inside the rotary kiln at the time of the pressure spike, and would include (a) combustion products such as water vapor, carbon dioxide, HCl, NO_x, and SO_2; (b) residuals and products of incomplete combustion (R&PICs) such as unburned organic vapors and carbon monoxide; and (c) ash particulates.

- A more severe case of incinerator fumes being released through the kiln seals and front wall chute would be in case of the ID fan failing off or being turned off during kiln operation (including loss of electric power). This occurs about three times per year at Hessische Industriemüll GmbH (HIM)/Biebersheim, mostly due to a sensitive control system used there. In this situation, the loss-of-vacuum and/or ID-fan-not-running interlocks should stop feeds to the kiln, so that the fume release to the area would be of short duration. However, if the interlocks failed to shut off the kiln feeds, the fume release could be more prolonged. Even in this situation, the operator would be expected to be alerted to the situation fairly promptly by multiple incineration system alarms and indications. No quantitative information on release rates or compositions has been made available from operational experience at HIM. However, it is judged that no significant offsite effects would be expected for this scenario, due to a relatively short duration of release.

- Fume releases from the incinerator stack can occur when the kiln feeds are suddenly cut off, such as when the loss-of-ID-fan or other interlock is tripped. The fumes dispersed from the stack would most likely consist only of R&PICs which are not removed by the gas-cleaning equipment. It was concluded during the HAZOPS discussions that such occasional releases might have some possible cumulative long-term health effects on the surrounding community (not studied as part of the hazard analysis), but would not have any significant acute health effects and thus were not considered further in the hazard analysis.

- The most significant scenario identified for fume releases from the incinerator stack was an extended low-temperature deviation in the kiln, e.g., due to loss of an organic feed stream or a major loss of primary combustion air. The R&PICs released from the stack were judged to possibly be able to cause reversible health effects to offsite persons downwind of the release; however, irreversible or lethal health effects would not be expected. The OWMC incinerator design has multiple levels of protection against low-temperature deviations, including alarms, interlocks, and auxiliary burners, so that the likelihood of such a release is expected to be low.

In summary, no incinerator fume release scenarios were identified during the HAZOPS which would be expected to result in offsite health effects more severe than reversible health effects, and the fume release rates and compositions were not further quantified.

E-8.0 DISPERSION OF GASES/VAPORS

The dispersion of the contaminants released into the atmosphere through the various accident scenarios was modeled in several ways. Variations of the general Gaussian plume model were used to model the concentrations of vapors or aerosols ($< 20\ \mu$ diameter) over the short term (periods up to an hour). The fume and fire scenarios were treated as point sources. The liquid spill scenarios were treated as ground-level sources and were modeled as a virtual source upwind of the actual source. The explosions were treated as instantaneous and were modeled as puff releases.

The basic Gaussian plume dispersion equation was used to model the point source, as follows (Turner, 1970):

$$X = \frac{Q}{\pi \sigma_y \sigma_z u}$$

where

X = concentration (g/m^3)

Q = emission rate (g/s)

σ_y = standard deviation of plume concentration distribution in the horizontal direction (m)

σ_z = standard deviation of plume concentration distribution in the vertical direction (m)

u = mean wind speed (m/s).

It was assumed that there is no effective plume rise and that concentrations are to be calculated for ground-level receptors, along the centerline of the plume. Formulas recommended by Briggs (Briggs, 1973) for calculating σ_y and σ_z values were used, assuming open-country conditions. These models and assumptions were considered to be sufficiently accurate for the purposes of assessing the consequences of accidental releases for the hazard analysis.

The dispersion calculations to determine concentrations as a function of distance from the source were performed by ORTECH International (formerly the Ontario Research Foundation). Concentrations for the fire scenarios were estimated for E and D Pasquill stability classes, with mean wind speeds of 2 m/s and 5 m/s, respectively. Receptors out to a distance of 5 km were considered. The ground-level fume or vapor release scenarios were modeled assuming E stability conditions and 2 m/s winds out to a distance of 5 km from the source.

The fume/vapor and fire scenario releases occur through building vents or, in the case of most of the fires, at heights well above ground level, were modeled using the following modification to the preceding equation:

$$x = \frac{Q}{\pi \sigma_y \sigma_z u} \exp\left[-\frac{1}{2} \left(\frac{H}{\sigma_z} \right)^2 \right]$$

where H is the effective emission height (m). As with the ground-level releases, the emission rates and release heights were estimated based on the facility characteristics and the accident scenarios. The fire scenarios were modeled assuming E and D stabilities, out to 25 km, and the vapor/fume releases were modeled assuming E stability, out to 25 km. The receptor distance was increased in the case of the elevated sources to account for the fact that the maximum concentrations attributable to these sources occur at a further distance downwind than from ground-level sources.

The liquid spill scenarios assumed that a liquid has formed a pool on the ground (of known dimension) and that the chemical constituents were subject to evaporation. The dispersion of the resulting vapors was calculated using equation (1) assuming a virtual point source for the pool. An initial horizontal standard deviation σ_{yo} can be calculated for an area source by $\sigma_{yo} = S/4.3$, where S is the cross-wind dimension of the source. These spills were modeled assuming E stability conditions, 2 m/s winds, for receptors located within 5 km of the source.

The dispersion of emissions from the ground-level explosion or other short-duration scenarios can be modeled using the following equation to approximate the release of a puff, or instantaneous source:

$$x = \frac{2 Q_T}{(2\pi)^{3/2} \sigma_x \sigma_y \sigma_z}$$

(Turner, 1970) where Q_T represents the total mass (g) of the release. Briggs's formulas for σ_y and σ_z for E stability conditions were used. σ_x

was assumed to be the same as σy. Initial dimensions of a puff should be approximated by assuming a virtual point source some distance upwind of the site of the explosion/release. However, the information required to do this was not available, and the releases were treated as point sources at the explosion/release site. Receptors located within 5 km were considered. The equation for explosions originating at elevated sources is

$$x = \frac{2 \; Q_T}{(2\pi)^{3/2} \sigma_x \; \sigma_y \; \sigma_z} \quad \exp \left[- \frac{1}{2} \left(\frac{H}{\sigma_z} \right)^2 \right]$$

where H is the effective height of release.

E-9.0 VAPOR CLOUD DEFLAGRATION

Accident scenarios have been identified that could result in the onsite release of hazardous chemicals from waste storage and treatment facilities. If these hazardous chemicals are also volatile and flammable, the accidental release could result in a deflagration and subsequent fires. As part of the offsite consequence analysis, estimations were made of the following:

- The maximum distance over which the atmosphere created by the hazardous chemical spill may be flammable
- The maximum distance at which the explosion of the flammable atmosphere created by the spill creates a hazard involving thermal radiation exposure.

The typical wastes can contain several different flammable materials, including

- Acetone
- Benzene
- Hexane
- Toluene.

To simplify the analysis, preliminary calculations were performed to identify the single flammable waste that gave rise to worst-case conditions. Data resulting from the worst-case scenario would then be used in the estimation of the offsite consequences of an onsite deflagration of vapors from a hazardous chemical spill.

Assumptions made to perform the calculations were as follows:

- The worst-case flammable material was 1,3 butadiene.
- Liquid spill area was maximized at a curbed area of 795 m^2.
- The diameter of the worst-case spill was estimated as the diameter of a circle with area equivalent to the spill area.
- The wind speed was 5 m/s.
- The atmospheric conditions during the accidental spill had a stable gustiness classification.

- The thermal output and radiation from the explosion were estimated by the amount of combustible material present at concentrations above the lower flammability limit.

- Ignition occurred instantaneously (1 second) only after the flammable gas/air cloud created by the spill had reached steady-state conditions.

- The center of the deflagration and thermal radiation release was taken as half of the plume centerline distance to the lower flammability limit.

- The fraction of combustion energy converted to radiant heat was 40 percent, which is ideal for flammable hydrocarbons.

- Atmospheric conditions during the explosive event remained in the stable gustiness category.

- The atmosphere was transparent, i.e., absorption of infrared thermal radiation by atmospheric water or carbon dioxide was negligible.

- The threshold for injury upon exposure to a radiant heat flux was 5 kW/m^2.

The evaluation procedure consisted of the following calculations:

1. The emission rate of chemical vapors released into the atmosphere as a result of the hazardous liquid spill was calculated using equations for evaporation and mass transfer reported by McKay and Matsugu (McKay, 1973). The Schmidt numbers required in the overall equation were approximated using a method given by Shen (Shen, 1982). Characteristics for the typical flammable substances considered were obtained from the Hazardous Chemicals Data Book (Weiss, 1980).

2. The maximum extension of the flammable zone, or the distance along the centerline to the lower flammability limit, was calculated using expressions reported by Burgess, et al (Burgess, 1975) and Pasquill (Pasquill, 1974). These calculations included the use of modified models for the atmospheric dispersion of volatile substances. Flammability limit data were obtained from the Hazardous Chemicals Data Book (Weiss, 1980).

3. The volume of flammable atmosphere contained in the dispersed cloud that could ignite and deflagrate, resulting in the release of thermal radiation, was calculated using approximations reported by Burgess, et al (Burgess, 1975).

4. The radiant heat flux generated by the explosion of the released flammable atmosphere was estimated using expressions developed by Mudan (Mudan, 1984).

5. Finally, the maximum distance from the center of the deflagration at which the release of thermal radiation still posed an injury hazard was calculated using information reported by Mudan (Mudan, 1984).

Based on these methods and assumptions, the maximum extension of the flammable zone was estimated to be about 75 m or less. The maximum distance for the onset of injury from exposure to thermal radiation was estimated to be about 1 m or less. Thus, even under deliberately worst-case conditions, the offsite consequences of an onsite deflagration of vapors from a hazardous chemical spill were determined to be negligible with regard to exposure to thermal radiation.

E-10.0 HEALTH EFFECTS OF OVERPRESSURE AND MISSILE IMPACTS

The severity of effects of an explosion event were evaluated by calculating the distance to a given blast overpressure, using standard overpressure curves (Bodurtha, 1980). The overpressure thresholds used in this study, as listed below, were obtained by reviewing a summary of available literature values for blast effects (Lees, 1980).

Loud noise: 0.04 psig overpressure

Window breakage: 0.15 psig overpressure

Reversible injury: 0.4 psig overpressure

Irreversible injury: 2.0 psig overpressure

It should be noted that the primary injury mechanisms at these blast overpressures are flying debris and structural damage, rather than direct blast injury.

E-11.0 HEALTH EFFECTS OF THERMAL RADIATION FROM FIRES

Accident scenarios have been identified which could lead to release of chemicals followed by confined pool fires within the proposed OWMC Treatment Facility. As part of the consequence analyses, the thermal radiation hazards from these pool fires (i.e., potential for burns) were estimated.

Typical wastes were specified for the consequence analyses for each of the waste categories that might be treated by the facility. To simplify the fire analyses, the chemical constituents of each typical waste were placed into the following groups:

- Flammable/combustible liquids
- Inerts -- water, pigments, dirt, and other noncombustibles.

The typical wastes contain several different types of flammable/combustible liquids including methyl ethyl ketone, oil, grease, tar, mineral spirits, solvents, toluene, acetone, etc. In order to further simplify the analyses, a single flammable liquid -- toluene -- was assumed to be present. Toluene is a conservative selection because its combustion generates more radiant heat than most of the other flammable liquids present in the typical waste. The amounts of flammable materials in each of the typical wastes is given in Table E-4.

Assumptions used in the calculations were as follows:

- Spill burns to completion (assumes no mitigation). It is important to note that all buildings storing or handling flammable materials will have appropriate fire detection/alarm systems and fire protection systems (e.g., sprinklers). External plant areas will be protected by a fire hydrant loop, water monitors, and a foam fire protection system. Successful operation of these protection systems would reduce (i.e., mitigate) but not completely eliminate the consequences of the scenario.

TABLE E-4. FLAMMABLE MATERIALS IN TYPICAL WASTES

Waste Category	Flammable Materials, wt.%	Inerts, wt.%
Organic halogenated waste	74.48	25.52
Aqueous organic waste	2.42	97.58
Organic nonpumpable wastes	36.75	63.25
Organic nonhalogenated solvents, oils and sludges	42.45	57.55
Blended liquids	46.85	53.15
Blended sludges	42.45	57.55
Segregated wastes	99.00	1.00
Inorganic acidic wastes	Not flammable	100
Inorganic alkali/neutral wastes*	0.49	99.51
Inorganic chromate wastes*	1.28	98.72
Inorganic cyanide wastes	Not flammable	100
Inorganic nonpumpable wastes**	0.77	99.23
Inorganic nonpumpable wastes (diluted with water)*	0.08	99.92

* Flammable only in receiving and storage areas. The organic content is assumed to be removed in the aqueous organic system. Thus, only nonflammable waste will be processed in the Physical/Chemical Treatment Plant.

** Applicable only in receiving area.

- All fires in the inorganic and organic unloading areas occur inside a building. The building ventilation system remains on during the fire (i.e., sufficient oxygen is available for complete combustion).
- A maximum height of the fire in the inorganic and organic unloading areas of 8 m.
- A wind velocity of 5 m/s for outdoor fires or 0 m/s for indoor fires.

The calculation procedures were as follows:

1). Calculate a time-weighted average pool diameter (for instantaneous spills only) using the correlation given by Mudan (Mudan, 1984). The maximum pool diameter is the diameter of the curbed area where the spill has occurred.

2). Calculate the pool diameter for continuous spill cases by the following equation:

$$\text{Pool diameter (m)} = \sqrt{\frac{4 \times \text{volume of flammable liquid } (m^3)}{\text{spill duration(s)} \times \pi \times \text{burn rate } (m/s)}}$$

The maximum pool diameter is the diameter of the curbed area where the spill has occurred. This assumes that the fire is initiated as a result of the accident causing the spill.

3). For outdoor fires, estimate flame height using equations from Thomas (Thomas, 1963). For indoor fires, a flame height equivalent to the building height of 8 m was assumed.

4). Calculate the flame tilt with the American Gas Association correlation cited by Mudan (Mudan, 1984).

5). Calculate the amount of radiant heated generated at the flame surface:

$$\text{Radiant heat } (kW/m^2) = \frac{0.35 \times 40{,}550 \times 0.000095 \times 866 \times \pi \times d^2}{4 \times \pi \times d \times (h + d / 4)}$$

where

d = pool diameter (m),

h = flame height (m),

0.35 = fraction of combustion heat converted to radiant heat

40,550 = heat of combustion of toluene (J/gm),

0.000095 = burn rate (m/s),

866 = liquid density (kg/m^3),

$\pi \times d \times (h + d / 4.0)$ = flame surface area (m^2),

6). Calculate transmissivity of the atmosphere assuming absorption of thermal radiation by water vapor (50 percent relative humidity) and carbon dioxide (partial pressure = 0.0003 atmospheres).

7). Calculate view factors for upwind, downwind, and crosswind locations applying the equations given by Mudan (Mudan, 1987).

8). Calculate thermal radiation levels at 5 m intervals away from the fire for upwind, crosswind, and downwind locations using data from Steps 5) through 7).

The thermal radiation levels were then used to determine the hazard distances and area affected for irreversible and lethal thresholds.

The irreversible threshold was taken as the upper limit for the onset of secondary burns. The irreversible threshold was assumed to be 6 kw/m^2 for fires lasting longer than 60 seconds (Mudan, 1984). For fires lasting less than 60 seconds, the following correlation was developed from data given by Mudan (Mudan, 1984):

$$\text{Irreversible Thermal Radiation } (kW/m^2) = \exp(-0.76307 \times \ln(\text{fire duration(sec)}) + 4.9545)$$

The lethal threshold was taken as the level which would be fatal to 1 percent of those exposed. It was assumed to be 10 kw/m^2 for fires lasting 60 seconds or longer (Mudan, 1984). For fires lasting less than 60 seconds the following correlation derived from data given by Mudan (Mudan, 1984) and Hymes (Hymes) was used:

$$\text{1\% Lethality Thermal Radiation } (kW/m^2) = \exp(-0.7186 \times \ln(\text{fire duration(sec)}) + 5.2448)$$

The areas at or above the lethal or irreversible thresholds were calculated assuming two half parabolas centered at the fire. The area, the up-wind, and the cross-wind distances are approximately correlated with the down-wind distance by the following relations:

IRREVERSIBLE

$\text{Area}(m^2) = 2.4371 \times (\text{down-wind distance})^2 - 12.846 \times (\text{down-wind distance}) + 16.477$

$\text{Up-wind distance (meters)} = 0.6658 \times (\text{downwind distance}) - 5.1075$

$\text{Cross-wind distance (meters)} = 0.9314 \times (\text{downwind distance}) - 2.0538$

LETHAL

$\text{Area}(m^2) = 2.2056 \times (\text{down-wind distance})^2 - 12.807 \times (\text{down-wind distance}) + 18.574$

$\text{Up-wind distance (meters)} = 0.5924 \times (\text{downwind distance}) - 4.4851$

$\text{Cross-wind distance (meters)} = 0.8818 \times (\text{downwind distance}) - 2.6364$

E-12.0 HEALTH EFFECTS FROM CHEMICAL BURNS

The chemical burn hazard for onsite personnel stems primarily from the corrosivity of wastes or reagents to the skin, or absorption of toxic materials through the skin, if a spill/splashing incident occurs. Information on chemical burn hazards for the various waste constituents and reagents was obtained from standard material safety data sources (USCG, 1984).

Chemical burn hazards are very localized, since skin contact with the spilled material is necessary for an injury to occur. Thus, only the persons in the immediate vicinity of the spill would be affected. It was not necessary to calculate an actual radius of effects for chemical burn hazards; instead, only the average number of onsite persons in the immediate vicinity of the spill location were counted as injuries. Chemical burn hazards will not extend to offsite populations, due to the distance from the spill locations (400 m minimum).

A number of chemical constituents of the typical waste streams can cause skin and/or eye irritation or dermatitis upon prolonged contact. Chemicals which would fall into this category are ammonium hydroxide, solvents (methyl ethyl ketone, trichloroethylene, toluene, xylene, acetone, and mineral spirits), esters, calcium hydroxide, and sodium hydroxide. More severe potential health effects are possible with a limited number of the typical waste constituents which are shown in Table E-5.

As can be seen from this table, most of the more dangerous chemicals with respect to skin contact are only present in low concentrations in the typical waste streams. Consequently, the severity of consequences for skin contact may be significantly reduced from the "Potential Effects" in the list. However, no attempt was made to quantify the reduced severity of skin contact effects for these chemicals as a function of concentration.

TABLE E-5. POTENTIAL HEALTH EFFECTS FROM CHEMICAL BURNS

Waste Category	Waste Constituent	Potential Effect
Aqueous organics	Phenol, 0.48%	Severe tissue burns; lethal amounts may be absorbed through skin
Organic halogenated	Methylene chloride, 1.50%	Very dangerous to eyes
Inorganic acidic wastes	Mineral acids, 21.07% (H_2SO_4, etc.)	Skin/eye chemical burns
Inorganic cyanide wastes	Sodium cyanide, 1.56%	Toxic via dermal route
Inorganic nonpumpables	Furfural, 0.19%	Dangerous to eye

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APPENDIX F

TOXICITY DATA USED IN CONSEQUENCE ANALYSES

APPENDIX F

TOXICITY DATA USED IN CONSEQUENCE ANALYSES

Short term toxicity criteria were developed for three levels of health effect: reversible effects; irreversible effects and lethality.

The reversible effects level is that level of exposure which, if exceeded, could cause non-debilitating effects that would not persist after exposure ceases. Reversible effects include irritation, headaches, drowsiness, nausea, light headedness, and difficulty with speech.

The irreversible effects level is the level of exposure which, if exceeded, could result in permanent damage to the exposed individual. At exposures slightly greater than the irreversible effect level, such damage may be clinically measurable, but not necessarily incapacitating. Exposures significantly greater than this level could be incapacitating or even cause death.

The lethal effects level is the level that would be expected to cause fatalities in at least some members of an exposed population.

ENVIRON, health risk consultant for OWMC, provided the data on the toxicity of airborne chemicals for the consequence analyses of this hazard analysis. The data in Tables F-1 through F-8 were used for estimating the summary of facility risk, at the three health effects levels, that is reported in Section 4.0 of this report. These toxicity data are being continually updated as new information becomes available, and will be incorporated when risk estimates are iterated for design/operation changes. Such changes in toxicity are not likely to have a significant impact on the overall risk estimates.

TABLE F-1. SHORT-TERM EXPOSURE LEVELS FOR CHLORINE (mg/m^3)

Effect	Population	5 min	Ref	15 min	Ref	30 min	Ref	60 min	Ref
Reversible, eye and respiratory tract irritation	Sensitive individuals in the General public	8.7	ENVIRON derived from NRC 1973	8.7	ENVIRON derived from NRC 1973	5.8	PEL NRC 1973	5.8	PEL NRC 1973
	HAOEP[a]	20	EEL Zielhuis 1970 NRC 1984	15	EEL Zielhuis 1970 NRC 1984	12	EEL Zielhuis 1970 NRC 1984	9	EEL Zielhuis 1970 NRC 1984
Irreversible, pulmonary function changes and eye damage	Sensitive individuals in the general public	29	ENVIRON	29	ENVIRON	15	ENVIRON	7	ENVIRON
	HAOEP[a]	145	ENVIRON	145	ENVIRON	73	IDLH NIOSH 1985	36	ENVIRON
Reportedly lethal to humans		1188	ENVIRON	396	ENVIRON	198	ENVIRON	99	Freitag 1941 (as cited in NRC 1984)

[a] Healthy Adults and Occupational and Emergency Personnel.

TABLE F-2. SHORT-TERM EXPOSURE LEVELS FOR HYDROGEN CHLORIDE (mg/m^3)

Effect	Population	5 min	Ref	15 min	Ref	30 min	Ref	60 min	Ref
Reversible; irritation of upper respiratory tract	Sensitive individuals in the general public	10	ENVIRON	10	ENVIRON	5	PEL NRC 1971	5	PEL NRC 1971
	HADEP[a]	75	NRC 1976	52	Stokinger 1981	15	NRC 1976	7.5	TLV-TWA ACGIH 1987
Irreversible; pulmonary function changes, burns	Sensitive individuals in the general public	60	ENVIRON	48	ENVIRON	30	ENVIRON	15	ENVIRON
	HADEP[a]	300	ENVIRON	240	ENVIRON	150	IDLH NIOSH 1985	75	ENVIRON
Reportedly lethal to humans		1500	Mason 1974	1375	ENVIRON	1225	ENVIRON	975	ENVIRON

[a] Healthy Adults and Occupational and Emergency Personnel.

TABLE F-3. SHORT-TERM EXPOSURE LEVELS FOR HYDROGEN SULFIDE (mg/m^3)

Effect	Population	5 min	Ref	15 min	Ref	30 min	Ref	60 min	Ref
Reversible; eye and respiratory tract irritation	Sensitive individuals in the general public	21	PEL NRC 1985	7	ENVIRON	3.5	ENVIRON	1.75	ENVIRON
	HAOEP[a]	70	EEGL NRC 1985	21	STEL ACGIH 1987	18	ENVIRON	14	TLV-TWA ACGIH 1987
Irreversible; corneal injury and pulmonary edema, unconsciousness	Sensitive Individuals in the General Public	56	ENVIRON	42	ENVIRON	28	ENVIRON	14	ENVIRON
	HAOEP[a]	280	Vanatta 1982	210	USEPA 1986	140	ENVIRON	70	NRC 1977 USEPA 1986
Reportedly lethal to humans		1400	ENVIRON	1400	McCabe and Clayton 1952	700	ENVIRON	350	ENVIRON

[a] Healthy Adults and Occupational and Emergency Personnel.

TABLE F-4. SHORT-TERM EXPOSURE LEVELS FOR NITROGEN DIOXIDE (mg/m^3)

Effect	Population	5 min	Ref	15 min	Ref	30 min	Ref	60 min	Ref
Reversible; respiratory tract irritation	Sensitive individuals in the general public	7.6	ENVIRON	7.6	ENVIRON	3.8	ENVIRON	1.9	SPEGL NRC 1985
	HAOEP[a]	30	ENVIRON	10	STEL ACGIH 1987	8	ENVIRON	6	TLV-TWA ACGIH 1987
Irreversible; pulmonary function changes	Sensitive individuals in the general public	38	ENVIRON	30	ENVIRON	19	ENVIRON	10	ENVIRON
	HAOEP[a]	190	ENVIRON	150	ENVIRON	95	IDLH NIOSH 1985	48	ENVIRON
Reportedly lethal to humans		282	NRC 1977	250	ENVIRON	235	ENVIRON	190	ACGIH 1976

[a] Healthy Adults and Occupational and Emergency Personnel.

TABLE F-5. SHORT-TERM EXPOSURE LEVELS FOR PHOSGENE (mg/m^3)

Effect	Population	5 min	Ref	15 min	Ref	30 min	Ref	60 min	Ref
Reversible, eye and respiratory tract irritation	Sensitive individuals in the general public	1.6	ENVIRON	0.64	ENVIRON	0.32	ENVIRON	0.16	ENVIRON
	HADEP[a]	8	EEL Zielhuis 1970 NRC 1984	3.2	EEL Zielhuis 1970 NRC 1984	1.6	EEL Zielhuis 1970 NRC 1984	0.8	EEL Zielhuis 1970 NRC 1984
Irreversible, pulmonary function changes	Sensitive individuals in the general public	32	ENVIRON	2.4	ENVIRON	1.6	ENVIRON	0.8	ENVIRON
	HADEP[a]	16	ENVIRON	12	ENVIRON	8	IDLH NIOSH 1985	4	ENVIRON
Reportedly lethal to humans		128	ENVIRON	43	ENVIRON	21	ENVIRON	11	ENVIRON

[a] Healthy Adults and Occupational and Emergency Personnel.

TABLE F-6. SHORT-TERM EXPOSURE LEVELS FOR POLYCHLORINATED BIPHENYLS (mg/m^3)

Effect	Population	5 min	Ref	15 min	Ref	30 min	Ref	60 min	Ref
Reversible	HAOEP[a]	6	ENVIRON	2	ENVIRON	1	ENVIRON	0.5	TLV-TWA ACGIH 1987
Irreversible	HAOEP[a]	10	ENVIRON	7.5	ENVIRON	5.0	IDLH NIOSH 1978	2.5	ENVIRON
Lethality		3600	ENVIRON	1200	ENVIRON	600	ENVIRON	300	ENVIRON

[a] Healthy Adults and Occupational Emergency Personnel.

TABLE F-7. SHORT-TERM EXPOSURE LEVELS FOR POLYCHLORINATED DIBENZOFURANS (mg/m3)

Effect	Population	5 min	Ref	15 min	Ref	30 min	Ref	60 min	Ref
Reversible	HAOEP[a]	2.9	ENVIRON	0.96	ENVIRON	0.48	ENVIRON	0.24	ENVIRON
Irreversible	HAOEP[a]	19.4	ENVIRON	6.4	ENVIRON	3.2	ENVIRON	1.6	ENVIRON
Reportedly lethal to monkeys		96	ENVIRON	32	ENVIRON	16	ENVIRON	8	ENVIRON

[a] Healthy Adults and Occupational and Emergency Personnel.

TABLE F-8. SHORT-TERM EXPOSURE LEVELS FOR SULFUR DIOXIDE (mg/m^3)

Effect	Population	5 min	Ref	15 min	Ref	30 min	Ref	60 min	Ref
Reversible, eye and respiratory tract irritation	Sensitive individuals in the general public	10	ENVIRON	10	STEL ACGIH 1987	7.5	ENVIRON	5	TLV-TWA ACGIH 1987
	HAOEP[a]	79	EEL NRC 1984	68	ENVIRON	52	EEL NRC 1984	26	EEL NRC 1984
Irreversible, pulmonary function changes	Sensitive individuals in the general public	78	ENVIRON	65	ENVIRON	52	ENVIRON	26	ENVIRON
	HAOEP[a]	390	ENVIRON	325	ENVIRON	260	IDLH NIOSH 1985	130	ENVIRON
Reportedly lethal to humans		2620	Thienes and Haley 1972	873	ENVIRON	436	ENVIRON	218	ENVIRON

[a] Healthy Adults and Occupational and Emergency Personnel.

APPENDIX G

EQUIPMENT FAILURE RATE AND HUMAN ERROR RATE DATA USED IN LIKELIHOOD ANALYSES

APPENDIX G

EQUIPMENT FAILURE RATE AND HUMAN ERROR RATE DATA USED IN LIKELIHOOD ANALYSES

This appendix presents the data values used in the frequency analysis of accidents with offsite consequences and the sources of the data. Each of the accidents was defined in terms of sets of events and/or conditions that must exist to permit the accident to occur. These events include plant specific information (such as the expected number of waste trucks to be handled), component failures (such as a valve failing open), and human errors (such as operator fails to close a valve). These events are listed below with the data value used in the analysis for that event, a verbal description of that event, and the source of the data value used for that event.

Failure and Error Rate Data and Data Sources

EVENT: "# 'NA' TANKS IN 'IS'"
DATA VALUE USED: 3.00E+01
EVENT DESCRIPTION: THE NUMBER OF STORAGE TANKS IN INORGANIC STORAGE USED TO STORE WASTE CLASS 'NA'
DATA VALUE SOURCE: OWMC PLANT DRAWINGS

EVENT: "# FLANGES BETWEEN 'OR' BULK & 'OS' IN 'OR'"
DATA VALUE USED: 1.20E+01
EVENT DESCRIPTION: NUMBER OF FLANGES IN ONE PIPE BETWEEN ORGANIC BULK RECEIVING AND ORGANIC STORAGE THAT ARE IN ORGANIC BULK RECEIVING AREA
DATA VALUE SOURCE: OWMC PLANT DRAWINGS, ASSUMED 1 FLANGE ON EITHER SIDE OF EACH VALVE OR PUMP

EVENT: "# FLANGES BETWEEN 'OR' DRUM & 'OS' IN 'OR'"
DATA VALUE USED: 7.00E+00
EVENT DESCRIPTION: NUMBER OF FLANGES IN ONE PIPE BETWEEN ORGANIC DRUM HANDLING AND ORGANIC STORAGE THAT ARE IN ORGANIC DRUM HANDLING AREA
DATA VALUE SOURCE: OWMC PLANT DRAWINGS, ASSUMED 1 FLANGE ON EITHER SIDE OF EACH VALVE OR PUMP

EVENT: "# FLANGES BETWEEN 'SW' BULK & 'OS' IN 'OR'"
DATA VALUE USED: 7.00E+00
EVENT DESCRIPTION: NUMBER OF FLANGES IN PIPE BETWEEN SEGREGATED BULK RECEIVING AND ORGANIC STORAGE THAT ARE IN SEGREGATED BULK RECEIVING AREA
DATA VALUE SOURCE: OWMC PLANT DRAWINGS, ASSUMED 1 FLANGE ON EITHER SIDE OF EACH VALVE OR PUMP

EVENT: "# OF AUTOBLOCK VALVES BETWEEN 'OR' BULK & 'OS'"
DATA VALUE USED: 1.00E+00
EVENT DESCRIPTION: NUMBER OF AUTOBLOCK VALVES IN ONE PIPE BETWEEN ORGANIC BULK RECEIVING AND ORGANIC STORAGE
DATA VALUE SOURCE: OWMC PLANT DRAWINGS. ASSUMPTION: 1 AUTOBLOCK VALVE ON DISCHARGE OF EACH PUMP

EVENT: "# OF AUTOBLOCK VALVES BETWEEN 'OR' BULK & 'OS' IN 'OR'"
DATA VALUE USED: 1.00E+00
EVENT DESCRIPTION: NUMBER OF AUTOBLOCK VALVES IN ONE PIPE BETWEEN ORGANIC BULK RECEIVING AND ORGANIC STORAGE THAT ARE IN ORGANIC BULK RECEIVING AREA
DATA VALUE SOURCE: OWMC PLANT DRAWINGS. ASSUMPTION: 1 AUTOBLOCK VALVE ON DISCHARGE OF EACH PUMP

EVENT: "# OF AUTOBLOCK VALVES BETWEEN 'OR' DRUM & 'OS'"
DATA VALUE USED: 1.00E+00
EVENT DESCRIPTION: NUMBER OF AUTOBLOCK VALVES IN ONE PIPE BETWEEN ORGANIC DRUM HANDLING AND ORGANIC STORAGE
DATA VALUE SOURCE: OWMC PLANT DRAWINGS. ASSUMPTION: 1 AUTOBLOCK VALVE ON DISCHARGE OF EACH PUMP

EVENT: "# OF AUTOBLOCK VALVES BETWEEN 'OR' DRUM & 'OS' IN 'OR'"
DATA VALUE USED: 1.00E+00
EVENT DESCRIPTION: NUMBER OF AUTOBLOCK VALVES IN ONE PIPE BETWEEN ORGANIC DRUM HANDLING AND ORGANIC STORAGE THAT ARE IN ORGANIC DRUM HANDLING AREA
DATA VALUE SOURCE: OWMC PLANT DRAWINGS. ASSUMPTION: 1 AUTOBLOCK VALVE ON DISCHARGE OF EACH PUMP

EVENT: "# OF AUTOBLOCK VALVES BETWEEN 'SW' BULK & 'OS'"
DATA VALUE USED: 1.00E+00
EVENT DESCRIPTION: NUMBER OF AUTOBLOCK VALVES IN ONE PIPE BETWEEN SEGREGATED BULK RECEIVING AND ORGANIC STORAGE
DATA VALUE SOURCE: OWMC PLANT DRAWINGS. ASSUMPTION: 1 AUTOBLOCK VALVE ON DISCHARGE OF EACH PUMP

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EVENT:              "# OF AUTOBLOCK VALVES BETWEEN 'SW' BULK & 'OS' IN 'OR'"
DATA VALUE USED:    1.00E+00
EVENT DESCRIPTION:  NUMBER OF AUTOBLOCK VALVES IN ONE PIPE BETWEEN SEGREGATED
                    BULK RECEIVING AND ORGANIC STORAGE THAT ARE IN SEGREGATED
                    BULK RECEIVING AREA
DATA VALUE SOURCE:  OWMC PLANT DRAWINGS. ASSUMPTION: 1 AUTOBLOCK VALVE ON
                    DISCHARGE OF EACH PUMP

EVENT:              "# OF MANUAL VALVES BETWEEN 'OR' BULK & 'OS'"
DATA VALUE USED:    8.00E+00
EVENT DESCRIPTION:  NUMBER OF MANUAL VALVES IN ONE PIPE BETWEEN ORGANIC BULK
                    RECEIVING AND ORGANIC STORAGE
DATA VALUE SOURCE:  OWMC PLANT DRAWINGS

EVENT:              "# OF MANUAL VALVES BETWEEN 'OR' BULK & 'OS' IN 'OR'"
DATA VALUE USED:    7.00E+00
EVENT DESCRIPTION:  NUMBER OF MANUAL VALVES IN ONE PIPE BETWEEN ORGANIC BULK
                    RECEIVING AND ORGANIC STORAGE THAT ARE IN ORGANIC BULK
                    RECEIVING AREA
DATA VALUE SOURCE:  OWMC PLANT DRAWINGS

EVENT:              "# OF MANUAL VALVES BETWEEN 'OR' DRUM & 'OS'"
DATA VALUE USED:    2.00E+00
EVENT DESCRIPTION:  NUMBER OF MANUAL VALVES IN ONE PIPE BETWEEN ORGANIC DRUM
                    HANDLING AND ORGANIC STORAGE
DATA VALUE SOURCE:  OWMC PLANT DRAWINGS

EVENT:              "# OF MANUAL VALVES BETWEEN 'OR' DRUM & 'OS' IN 'OR'"
DATA VALUE USED:    1.00E+00
EVENT DESCRIPTION:  NUMBER OF MANUAL VALVES IN ONE PIPE BETWEEN ORGANIC DRUM
                    HANDLING AND ORGANIC STORAGE THAT ARE IN ORGANIC DRUM
                    HANDLING AREA
DATA VALUE SOURCE:  OWMC PLANT DRAWINGS

EVENT:              "# OF MANUAL VALVES BETWEEN 'SW' BULK & 'OS'"
DATA VALUE USED:    2.00E+00
EVENT DESCRIPTION:  NUMBER OF MANUAL VALVES IN ONE PIPE BETWEEN SEGREGATED BULK
                    RECEIVING AND ORGANIC STORAGE
DATA VALUE SOURCE:  OWMC PLANT DRAWINGS

EVENT:              "# OF MANUAL VALVES BETWEEN 'SW' BULK & 'OS' IN 'OR'"
DATA VALUE USED:    1.00E+00
EVENT DESCRIPTION:  NUMBER OF MANUAL VALVES IN ONE PIPE BETWEEN SEGREGATED BULK
                    RECEIVING AND ORGANIC STORAGE THAT ARE IN SEGREGATED BULK
                    RECEIVING AREA
DATA VALUE SOURCE:  OWMC PLANT DRAWINGS
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EVENT: "# OF MOTOR OPERATED VALVES BETWEEN 'OR' BULK & 'OS'"
DATA VALUE USED: 1.00E+00
EVENT DESCRIPTION: NUMBER OF MOTOR OPERATED VALVES IN ONE PIPE BETWEEN ORGANIC BULK RECEIVING AND ORGANIC STORAGE
DATA VALUE SOURCE: OWMC PLANT DRAWINGS

EVENT: "# OF MOTOR OPERATED VALVES BETWEEN 'OR' BULK & 'OS' IN 'OR'"
DATA VALUE USED: 0.00E+00
EVENT DESCRIPTION: NUMBER OF MOTOR OPERATED VALVES IN ONE PIPE BETWEEN ORGANIC BULK RECEIVING AND ORGANIC STORAGE THAT ARE IN ORGANIC BULK RECEIVING AREA
DATA VALUE SOURCE: OWMC PLANT DRAWINGS

EVENT: "# OF MOTOR OPERATED VALVES BETWEEN 'OR' DRUM & 'OS'"
DATA VALUE USED: 1.00E+00
EVENT DESCRIPTION: NUMBER OF MOTOR OPERATED VALVES IN ONE PIPE BETWEEN ORGANIC DRUM HANDLING AND ORGANIC STORAGE
DATA VALUE SOURCE: OWMC PLANT DRAWINGS

EVENT: "# OF MOTOR OPERATED VALVES BETWEEN 'OR' DRUM & 'OS' IN 'OR'"
DATA VALUE USED: 0.00E+00
EVENT DESCRIPTION: NUMBER OF MOTOR OPERATED VALVES IN ONE PIPE BETWEEN ORGANIC DRUM HANDLING AND ORGANIC STORAGE THAT ARE IN ORGANIC DRUM HANDLING AREA
DATA VALUE SOURCE: OWMC PLANT DRAWINGS

EVENT: "# OF MOTOR OPERATED VALVES BETWEEN 'SW' BULK & 'OS'"
DATA VALUE USED: 1.00E+00
EVENT DESCRIPTION: NUMBER OF MOTOR OPERATED VALVES IN ONE PIPE BETWEEN SEGREGATED BULK RECEIVING AND ORGANIC STORAGE
DATA VALUE SOURCE: OWMC PLANT DRAWINGS

EVENT: "# OF MOTOR OPERATED VALVES BETWEEN 'SW' BULK & 'OS' IN 'OR'"
DATA VALUE USED: 0.00E+00
EVENT DESCRIPTION: NUMBER OF MOTOR OPERATED VALVES IN ONE PIPE BETWEEN SEGREGATED BULK RECEIVING AND ORGANIC STORAGE THAT ARE IN SEGREGATED BULK RECEIVING AREA
DATA VALUE SOURCE: OWMC PLANT DRAWINGS

EVENT: "'HW' DRUM HANDLED FREQ"
DATA VALUE USED: 3.23E+03
EVENT DESCRIPTION: NUMBER OF 'HW' DRUMS HANDLED PER YEAR (BASED ON 150,000 T/A PLANT THROUGHPUT)
DATA VALUE SOURCE: OWMC TREATMENT FACILITY, ANNUAL OPERATIONS SUMMARY, MONENCO LETTER DATED 10 MARCH 88, UPDATED BY MONENCO TELEX DATED 21 MARCH 88

EVENT: "'HW' DRUM HANDLED LAST PROB"
DATA VALUE USED: 9.30E-02
EVENT DESCRIPTION: PROBABILITY THAT 'HW' DRUM WAS LAST DRUM PROCESSED
DATA VALUE SOURCE: OWMC TREATMENT FACILITY, ANNUAL OPERATIONS SUMMARY, MONENCO LETTER DATED 10 MARCH 88, UPDATED BY MONENCO TELEX DATED 21 MARCH 88

EVENT: "'HW' DRUM NOT NEEDED FOR RECIPE PROB"
DATA VALUE USED: 3.00E-02
EVENT DESCRIPTION: 'HW' DRUM IS RECEIVED THAT IS NOT CURRENTLY NEEDED FOR INCINERATOR RECIPE
DATA VALUE SOURCE: ASSUMPTION: 1 IN 100 DRUMS NOT IMMEDIATELY NEEDED

EVENT: "'HW' FLUID THIXOTROPIC BLOCKS PIPE PROB"
DATA VALUE USED: 0.00E+00
EVENT DESCRIPTION: THIXOTROPIC "'HW' FLUID BLOCKS PIPE WHEN PUMPED
DATA VALUE SOURCE: SELECTION OF TYPICAL WASTE (INPUT TO HAZARD ANALYSIS) DOCUMENT # DR-03-00-02. MONENCO REPORT DATED 23 FEB 88

EVENT: "'HW' STORAGE TO BLEND FREQ"
DATA VALUE USED: 4.43E+02
EVENT DESCRIPTION: NUMBER OF TRANSFERS OF 'HW' FROM STORAGE TO BLENDING TANK PER YEAR (BASED ON 150,000 T/A PLANT THROUGHPUT)
DATA VALUE SOURCE: OWMC TREATMENT FACILITY, ANNUAL OPERATIONS SUMMARY, MONENCO LETTER DATED 10 MARCH 88, UPDATED BY MONENCO TELEX DATED 21 MARCH 88; OWMC PLANT DRAWINGS. ASSUMPTION: STORAGE TANK WOULD BE TRANSFERRED WHEN 1/2 FULL. TOTAL AMOUNT OF 'HW' PER YEAR = 1771 CUBIC METERS. EACH TRANSFER IS OF 4 CUBIC METERS. NUMBER OF TRANSFERS = 1771 / 4 = 443.

EVENT: "'HW' STORAGE TO P/C FREQ"
DATA VALUE USED: 0.00E+00
EVENT DESCRIPTION: NUMBER OF TRANSFERS OF 'HW' FROM STORAGE TO PHYS/CHEM TREATMENT PER YEAR (BASED ON 150,000 T/A PLANT THROUGHPUT)
DATA VALUE SOURCE: OWMC PLANT DRAWINGS - NO LINE TO PHYS/CHEM EXISTS AT STORAGE TANK.

EVENT: "'HW' STORAGE TO PHASE SEP FREQ"
DATA VALUE USED: 0.00E+00
EVENT DESCRIPTION: NUMBER OF TRANSFERS OF 'HW' FROM STORAGE TO PHASE SEPARATION PER YEAR (BASED ON 150,000 T/A PLANT THROUGHPUT)
DATA VALUE SOURCE: OWMC PLANT DRAWINGS - NO LINE TO PHASE SEPARATION EXISTS AT STORAGE TANK.

EVENT: "'HW' TRANSFERRED TO P/C FROM BULK UNLOAD PROB"
DATA VALUE USED: 0.00E+00
EVENT DESCRIPTION: NUMBER OF TRANSFERS OF 'HW' FROM BULK UNLOADING TO PHASE SEPARATION PER YEAR (BASED ON 150,000 T/A PLANT THROUGHPUT)
DATA VALUE SOURCE: OWMC PLANT DRAWINGS - NO LINE TO PHYS/CHEM EXISTS AT STORAGE TANK. ASSUMPTION: INTENTION IS TO NEVER SEND 'HW' TO PHYS/CHEM

EVENT: "'HW' TRUCK PUMPED OUT FREQ"
DATA VALUE USED: 7.50E+01
EVENT DESCRIPTION: NUMBER OF 'HW' TRUCKS PUMPED OUT PER YEAR (BASED ON 150,000 T/A PLANT THROUGHPUT)
DATA VALUE SOURCE: OWMC TREATMENT FACILITY, ANNUAL OPERATIONS SUMMARY, MONENCO LETTER DATED 10 MARCH 88, UPDATED BY MONENCO TELEX DATED 21 MARCH 88

EVENT: "'HW' TRUCK PUMPED OUT LAST PROB"
DATA VALUE USED: 4.70E-02
EVENT DESCRIPTION: PROBABILITY THAT 'HW' TRUCK WAS LAST TRUCK PROCESSED
DATA VALUE SOURCE: OWMC TREATMENT FACILITY, ANNUAL OPERATIONS SUMMARY, MONENCO LETTER DATED 10 MARCH 88, UPDATED BY MONENCO TELEX DATED 21 MARCH 88

EVENT: "'IN' TRUCK PUMPED OUT FREQ"
DATA VALUE USED: 2.19E+03
EVENT DESCRIPTION: NUMBER OF 'IN' TRUCKS UNLOADED PER YEAR (BASED ON 150,000 T/A PLANT THROUGHPUT)
DATA VALUE SOURCE: OWMC TREATMENT FACILITY, ANNUAL OPERATIONS SUMMARY, MONENCO LETTER DATED 10 MARCH 88, UPDATED BY MONENCO TELEX DATED 21 MARCH 88

EVENT: "'NA' TRUCK PUMPED OUT LAST PROB"
DATA VALUE USED: 4.50E-01
EVENT DESCRIPTION: PROBABILITY THAT 'NA' TRUCK WAS LAST TRUCK PROCESSED
DATA VALUE SOURCE: OWMC TREATMENT FACILITY, ANNUAL OPERATIONS SUMMARY, MONENCO LETTER DATED 10 MARCH 88, UPDATED BY MONENCO TELEX DATED 21 MARCH 88

EVENT: "'ON' DRUM HANDLED FREQ"
DATA VALUE USED: 3.37E+04
EVENT DESCRIPTION: NUMBER OF 'ON' DRUMS HANDLED PER YEAR (BASED ON 150,000 T/A PLANT THROUGHPUT)
DATA VALUE SOURCE: OWMC TREATMENT FACILITY, ANNUAL OPERATIONS SUMMARY, MONENCO LETTER DATED 10 MARCH 88, UPDATED BY MONENCO TELEX DATED 21 MARCH 88

EVENT: "'ON' DRUM NOT NEEDED FOR RECIPE PROB"
DATA VALUE USED: 0.00E+00
EVENT DESCRIPTION: 'ON' DRUM IS RECEIVED THAT IS NOT CURRENTLY NEEDED FOR INCINERATOR RECIPE
DATA VALUE SOURCE: ASSUMPTION: 'ON' DRUMS CAN BE HANDLED AT ANY TIME

EVENT: "'OR' BULK UNDERGROUND TANK EMPTY PROB"
DATA VALUE USED: 9.46E-01
EVENT DESCRIPTION: PROBABILITY THAT WASTE UNLOAD TANK AT TYPE B UNLOAD IS NOT IN USE AT A GIVEN TIME. THIS TANK IS USED AS SLOP TANK OFF THE SUMP OF TYPE A UNLOAD.
DATA VALUE SOURCE: OWMC TREATMENT FACILITY, ANNUAL OPERATIONS SUMMARY, MONENCO LETTER DATED 10 MARCH 88, UPDATED BY MONENCO TELEX DATED 21 MARCH 88. 'WSSL' RECEIPT 217/YR, .868/DAY, 1 HOUR PER UNLOAD, 8 HOUR DAY, PROBABILITY OF 'WSSL' AT UNLOAD BAY .1085. ASSUMPTION: 1/2 'WSSL' TRUCKS DUMP TO UNLOAD TANK. .1085/2 = .0543 = PROBABILITY IN USE.

EVENT: "'OR' BULK UNDERGROUND TANK FULL PROB"
DATA VALUE USED: 5.43E-02
EVENT DESCRIPTION: PROBABILITY THAT WASTE UNLOAD TANK AT TYPE B UNLOAD IS IN USE AT A GIVEN TIME. THIS TANK IS USED AS SLOP TANK OFF THE SUMP OF TYPE A UNLOAD.
DATA VALUE SOURCE: OWMC TREATMENT FACILITY, ANNUAL OPERATIONS SUMMARY, MONENCO LETTER DATED 10 MARCH 88, UPDATED BY MONENCO TELEX DATED 21 MARCH 88. 'WSSL' RECEIPT 217/YR, .868/DAY, 1 HOUR PER UNLOAD, 8 HOUR DAY, PROBABILITY OF 'WSSL' AT UNLOAD BAY .1085. ASSUMPTION: 1/2 'WSSL' TRUCKS DUMP TO UNLOAD TANK. .1085/2 = .0543 = PROBABILITY IN USE.

EVENT: "'SW' DRUM HANDLED FREQ"
DATA VALUE USED: 4.70E+01
EVENT DESCRIPTION: NUMBER OF 'SW' DRUMS HANDLED PER YEAR (BASED ON 150,000 T/A PLANT THROUGHPUT)
DATA VALUE SOURCE: OWMC TREATMENT FACILITY, ANNUAL OPERATIONS SUMMARY, MONENCO LETTER DATED 10 MARCH 88, UPDATED BY MONENCO TELEX DATED 21 MARCH 88

EVENT: "'SW' DRUM NOT NEEDED FOR RECIPE PROB"
DATA VALUE USED: 0.00E+00
EVENT DESCRIPTION: 'SW' DRUM IS RECEIVED THAT IS NOT CURRENTLY NEEDED FOR INCINERATOR RECIPE
DATA VALUE SOURCE: ASSUMPTION: 'SW' DRUMS WILL RECEIVE TOP PRIORITY

EVENT: "'SW' FLUID THIXOTROPIC BLOCKS PIPE PROB"
DATA VALUE USED: 0.00E+00
EVENT DESCRIPTION: THIXOTROPIC "'SW' FLUID BLOCKS PIPE WHEN PUMPED
DATA VALUE SOURCE: SELECTION OF TYPICAL WASTE (INPUT TO HAZARD ANALYSIS) DOCUMENT # DR-03-00-02. MONENCO REPORT DATED 23 FEB 88

EVENT: "'SW' TRUCK PUMPED OUT FREQ"
DATA VALUE USED: 2.00E+00
EVENT DESCRIPTION: NUMBER OF 'SW' TRUCKS PUMPED OUT PER YEAR (BASED ON 150,000 T/A PLANT THROUGHPUT)
DATA VALUE SOURCE: OWMC TREATMENT FACILITY, ANNUAL OPERATIONS SUMMARY, MONENCO LETTER DATED 10 MARCH 88, UPDATED BY MONENCO TELEX DATED 21 MARCH 88

EVENT: "'SW' TRUCK PUMPED OUT LAST PROB"
DATA VALUE USED: 1.00E+00
EVENT DESCRIPTION: PROBABILITY THAT 'SW' TRUCK WAS LAST TRUCK PROCESSED
DATA VALUE SOURCE: OWMC TREATMENT FACILITY, ANNUAL OPERATIONS SUMMARY, MONENCO LETTER DATED 10 MARCH 88, UPDATED BY MONENCO TELEX DATED 21 MARCH 88

EVENT: "'WS' XFERRED FROM PHYS/CHEM FREQ"
DATA VALUE USED: 3.25E+02
EVENT DESCRIPTION: NUMBER OF TRANSFERS OF 'WS' FROM PHYS/CHEM TREATMENT TO STORAGE PER YEAR (BASED ON 150,000 T/A PLANT THROUGHPUT)
DATA VALUE SOURCE: OWMC PLANT DRAWINGS - PROCESS FLOW DIAGRAMS

EVENT: "'WS' XFERRED TO PHYS/CHEM FREQ"
DATA VALUE USED: 0.00E+00
EVENT DESCRIPTION: NUMBER OF TRANSFERS OF 'WS' FROM STORAGE TO PHYS/CHEM TREATMENT PER YEAR (BASED ON 150,000 T/A PLANT THROUGHPUT)
DATA VALUE SOURCE: NOT EXPECTED FOR TYPICAL WASTE

EVENT: "1/# 'OR' BULK TRUCK UNLOADS PER DAY"
DATA VALUE USED: 2.02E-01
EVENT DESCRIPTION: PROBABILITY THAT GIVEN 'OR' TRUCK UNLOAD IS FIRST OF DAY
DATA VALUE SOURCE: OWMC TREATMENT FACILITY, ANNUAL OPERATIONS SUMMARY, MONENCO LETTER DATED 10 MARCH 88, UPDATED BY MONENCO TELEX DATED 21 MARCH 88

EVENT: "1/# 'OR' DRUM VAC TANK UNLOADS PER DAY"
DATA VALUE USED: 1.81E-01
EVENT DESCRIPTION: PROBABILITY THAT GIVEN 'OR' DRUM VACUUM TANK UNLOAD IS FIRST OF DAY
DATA VALUE SOURCE: OWMC TREATMENT FACILITY, ANNUAL OPERATIONS SUMMARY, MONENCO LETTER DATED 10 MARCH 88, UPDATED BY MONENCO TELEX DATED 21 MARCH 88

EVENT: "1/# 'SW' BULK TRUCK UNLOADS PER DAY"
DATA VALUE USED: 1.25E+02
EVENT DESCRIPTION: PROBABILITY THAT GIVEN 'OR' TRUCK UNLOAD IS FIRST OF DAY
DATA VALUE SOURCE: OWMC TREATMENT FACILITY, ANNUAL OPERATIONS SUMMARY, MONENCO LETTER DATED 10 MARCH 88, UPDATED BY MONENCO TELEX DATED 21 MARCH 88

EVENT: "10 DRUMS IGNITE IF EXPOSED TO FIRE PROB"
DATA VALUE USED: 1.00E-02
EVENT DESCRIPTION: 10 DRUMS IN DRUMS STORAGE IGNITE IN THE EVENT OF A FIRE CAUSED BY THE SPILL AND IGNITION OF 1 DRUM OF WASTE
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "AGITATOR IMPELLER FALLS OFF FREQ"
DATA VALUE USED: 3.00E-03
EVENT DESCRIPTION: TANK AGITATOR SEPARATES FROM SHAFT
DATA VALUE SOURCE: PROPRIETARY DATA SOURCE - 1/300 YR PUMP IMPELLER FAILURE RATE (RWJ)

EVENT: "ALL DRUMS ON PALLET FAIL IN HANDLING ACCIDENT PROB"
DATA VALUE USED: 4.00E-03
EVENT DESCRIPTION: THE PROBABILITY THAT GIVEN A FORKLIFT ACCIDENT INVOLVING A PALLET, ALL DRUMS ON PALLET FAIL
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "AT DRUM PUMPOUT STATION (10-11) - DRUM NOT PUMPED OUT - H.E.PROB"
DATA VALUE USED: 3.00E-02
EVENT DESCRIPTION: OPERATOR DOES NOT PUMP OUT A DRUM AT THE DRUM PUMPOUT STATION
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "AUTOBLOCK VALVE FAILS CLOSED PROB"
DATA VALUE USED: 1.00E-04
EVENT DESCRIPTION: PUMP AUTOBLOCK VALVE FAILS TO OPEN, OR FAILS CLOSED AFTER OPENING
DATA VALUE SOURCE: RASMUSSEN ET AL., "REACTOR SAFETY STUDY", APPENDIX III - FAILURE DATA, USAEC; WASH-1400 (1975)

EVENT: "AUTOBLOCK VALVE FAILS OPEN PROB"
DATA VALUE USED: 1.00E-04
EVENT DESCRIPTION: PUMP AUTOBLOCK VALVE FAILS OPEN WHEN SUPPOSED TO BE CLOSED
DATA VALUE SOURCE: RASMUSSEN ET AL., "REACTOR SAFETY STUDY", APPENDIX III - FAILURE DATA, USAEC; WASH-1400 (1975)

EVENT: "BULK TRUCK PUMPED DRY PROB"
DATA VALUE USED: 1.00E-01
EVENT DESCRIPTION: UNLOAD PUMP RUNS TOO LONG, CONTINUES TO RUN AFTER PUMPING OUT TRUCK
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "C.S. LINE BREAKAGE UNDER HIGH PRESSURE PROB"
DATA VALUE USED: 1.00E-02
EVENT DESCRIPTION: GIVEN A HIGH LINE PRESSURE, PROBABILITY THAT A CARBON STEEL PIPE WILL RUPTURE
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "C.S. LINE LEAK FREQ"
DATA VALUE USED: 8.80E-06
EVENT DESCRIPTION: FREQUENCY OF CARBON STEEL PIPE LEAKS (PER YEAR, PER METER)
DATA VALUE SOURCE: PROPRIETARY DATA (ERZ)

EVENT: "C.S. PIPE LEAK LEADS TO PIPE BREAK PROB"
DATA VALUE USED: 1.00E-01
EVENT DESCRIPTION: PROBABILITY THAT IF A PIPE IS LEAKING, THAT IT WILL RUPTURE
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "COUPLING ON HOSE CONNECTION NOT TIGHTENED - LEAKS - PROB"
DATA VALUE USED: 5.00E-03
EVENT DESCRIPTION: COUPLING ON HOSE CONNECTION TO TRUCK LEAKS DUE TO NOT BEING TIGHTENED
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "DAMAGED COUPLING ON HOSE CONNECTION - LEAKS - PROB"
DATA VALUE USED: 1.00E-03
EVENT DESCRIPTION: COUPLING ON HOSE CONNECTION TO TRUCK LEAKS DUE TO DAMAGE TO THE COUPLING
DATA VALUE SOURCE: HOSE CONNECTOR - 1E-02/YR * # OF TRANSFERS PER YEAR. "HAZARDOUS WASTE TANK FAILURE AND RELEASE MODEL", POPE-REID ASSOCIATES, INC., JAN 86. DOCUMENT PB86-192945.

EVENT: "DEAD-HEADED CENTR. PUMP CAUSES C.S. PIPE FAILURE PROB"
DATA VALUE USED: 1.00E-02
EVENT DESCRIPTION: PROBABILITY THAT A DEAD-HEADED CENTRIFUGAL PUMP GENERATES A HIGH ENOUGH PRESSURE TO RUPTURE A CARBON STEEL PIPE
DATA VALUE SOURCE: ENGINEERING JUDGMENT

EVENT: "DEAD-HEADED CENTR. PUMP CAUSES PUMP SEAL LEAKAGE PROB"
DATA VALUE USED: 8.00E-01
EVENT DESCRIPTION: PROBABILITY THAT A DEAD-HEADED CENTRIFUGAL PUMP RESULTS IN PUMP SEAL LEAKAGE
DATA VALUE SOURCE: ENGINEERING JUDGMENT

EVENT: "DRUM EXPECTED TO BE EMPTY IS SPILLED PROB"
DATA VALUE USED: 1.00E-03
EVENT DESCRIPTION: PROBABILITY THAT AN OPERATOR HANDLING A PARTIALLY FULL DRUM EXPECTED TO BE EMPTY SPILLS THE CONTENTS OF THE DRUM
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "DRUM HANDLING ACCIDENT PROB"
DATA VALUE USED: 2.00E-06
EVENT DESCRIPTION: FREQUENCY OF ACCIDENTS INVOLVING THE HANDLING OF DRUMS
DATA VALUE SOURCE: HIM PLANT DATA

EVENT: "DRUM NOT TAGGED - H.E.PROB"
DATA VALUE USED: 1.00E-04
EVENT DESCRIPTION: OPERATOR FAILS TO TAG A DRUM
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "DRUM PUMPOUT STOPPED TOO SOON - H.E.PROB"
DATA VALUE USED: 1.00E-03
EVENT DESCRIPTION: OPERATOR DOES NOT FULLY PUMP OUT A DRUM - STOPS TOO SOON
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "DRUM PUMPOUT STOPPED TOO SOON-OPER CAN'T HEAR DRUM EMPTIED - H.E.PROB"
DATA VALUE USED: 1.00E-03
EVENT DESCRIPTION: OPERATOR DOES NOT FULLY PUMP OUT A DRUM BECAUSE HE CANNOT HEAR NOISE FROM THE SUCTION LINE
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "DRUM RUPTURES WHEN PLACED IN STG PROB"
DATA VALUE USED: 1.00E-06
EVENT DESCRIPTION: SPONTANEOUS RUPTURE OF A DRUM PLACED IN STORAGE
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "DRUM RUPTURES WHEN STORED TOO LONG PROB"
DATA VALUE USED: 1.00E-04
EVENT DESCRIPTION: SPONTANEOUS RUPTURE OF A DRUM PLACED IN STORAGE FOR A LONG PERIOD OF TIME
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "DRUM TAG LOST OR DAMAGED PROB"
DATA VALUE USED: 1.00E-04
EVENT DESCRIPTION: PROBABILITY THAT A DRUM TAG IS LOST OR SEVERELY DAMAGED
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "FAULTY CONDUCTION THROUGH TRUCK GROUND PROB"
DATA VALUE USED: 5.00E-03
EVENT DESCRIPTION: PROBABILITY THAT THE GROUNDING SYSTEM HAS FAILED WHEN GROUNDING A TRUCK
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "FIRE IN DRUM STG EXPANDS DUE TO FIRE PROTECTION SYSTEM INEFFECTIVE PROB"
DATA VALUE USED: 1.00E-01
EVENT DESCRIPTION: GIVEN A FIRE IN DRUM STORAGE, THE PROBABILITY THAT THE FIRE WILL IGNITE 100 DRUMS OF WASTE, PRIMARILY DUE TO FAILURE OF FIRE PROTECTION SYSTEM
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "FLAMMABLE VAPORS PRESENT IN/AROUND 'HW' TRUCK PROB"
DATA VALUE USED: 1.00E+00
EVENT DESCRIPTION: PROBABILITY THAT FLAMMABLE VAPORS ARE PRESENT IN/AROUND AN 'HW' TRUCK WHILE IT IS BEING UNLOADED
DATA VALUE SOURCE: SELECTION OF TYPICAL WASTE (INPUT TO HAZARD ANALYSIS) DOCUMENT # DR-03-00-02. MONENCO REPORT DATED 23 FEB 88

EVENT: "FLAMMABLE VAPORS PRESENT IN/AROUND 'SW' TRUCK PROB"
DATA VALUE USED: 1.00E+00
EVENT DESCRIPTION: PROBABILITY THAT FLAMMABLE VAPORS ARE PRESENT IN/AROUND AN 'SW' TRUCK WHILE IT IS BEING UNLOADED
DATA VALUE SOURCE: SELECTION OF TYPICAL WASTE (INPUT TO HAZARD ANALYSIS) DOCUMENT # DR-03-00-02. MONENCO REPORT DATED 23 FEB 88

EVENT: "FLANGE LEAK FREQ"
DATA VALUE USED: 4.40E-03
EVENT DESCRIPTION: FREQUENCY OF PIPE FLANGE LEAKS
DATA VALUE SOURCE: GREEN AND BOWINE, "RELIABILITY TECHNOLOGY", WILEY (1972)

EVENT: "FLUSH CONNECTION LEFT OPEN H.E.PROB"
DATA VALUE USED: 4.00E-03
EVENT DESCRIPTION: OPERATOR FAILS TO CLOSE FLUSH CONNECTION AFTER FLUSH
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "FLUSH OF 'HW' IN LINE NOT EFFECTIVE PROB"
DATA VALUE USED: 1.00E-02
EVENT DESCRIPTION: FLUSH OF LINE CONTAINING 'HW' WASTE IS PARTIALLY OR TOTALLY INEFFECTIVE
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "FLUSH PARTIALLY INEFFECTIVE PROB"
DATA VALUE USED: 7.00E-01
EVENT DESCRIPTION: GIVEN THAT A FLUSH OF A LINE CONTAINING 'HW' WASTE IS PARTIALLY OR TOTALLY INEFFECTIVE, PROBABILITY THAT IT IS ONLY PARTIALLY INEFFECTIVE
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "FLUSH TOTALLY INEFFECTIVE PROB"
DATA VALUE USED: 3.00E-01
EVENT DESCRIPTION: GIVEN THAT A FLUSH OF A LINE CONTAINING 'HW' WASTE IS PARTIALLY OR TOTALLY INEFFECTIVE, PROBABILITY THAT IT IS TOTALLY INEFFECTIVE
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "FRACTION OF PIPE LENGTH BETWEEN 'OR' BULK AND 'OS' IN 'OR'"
DATA VALUE USED: 1.67E-01
EVENT DESCRIPTION: FRACTION OF PIPE LENGTH BETWEEN BULK ORGANIC RECEIVING AND ORGANIC STORAGE IN ORGANIC RECEIVING
DATA VALUE SOURCE: ESTIMATED FROM OWMC PLANT DRAWING

EVENT: "FRACTION OF PIPE LENGTH BETWEEN 'OR' DRUM AND 'OS' IN 'OR'"
DATA VALUE USED: 2.03E-01
EVENT DESCRIPTION: FRACTION OF PIPE LENGTH BETWEEN DRUM ORGANIC RECEIVING AND ORGANIC STORAGE IN ORGANIC RECEIVING
DATA VALUE SOURCE: ESTIMATED FROM OWMC PLANT DRAWING

EVENT: "FRACTION OF YEAR 'HW' TRUCK AT UNLOAD"
DATA VALUE USED: 8.50E-03
EVENT DESCRIPTION: FRACTION OF A YEAR THAT AN 'HW' TRUCK IS AT AN UNLOAD BAY
DATA VALUE SOURCE: OWMC TREATMENT FACILITY, ANNUAL OPERATIONS SUMMARY, MONENCO LETTER DATED 10 MARCH 88, UPDATED BY MONENCO TELEX DATED 21 MARCH 88

EVENT: "FRACTION OF YEAR TEMPERATURE BELOW FREEZING"
DATA VALUE USED: 3.30E-01
EVENT DESCRIPTION: FRACTION OF YEAR AIR TEMPERATURE IS BELOW FREEZING
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "FROZEN C.S. PIPE RUPTURES PROB"
DATA VALUE USED: 7.00E-01
EVENT DESCRIPTION: PROBABILITY THAT A FROZEN CARBON STEEL PIPE RUPTURES
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "HEAT TRACING FAILURE FREQ/HR"
DATA VALUE USED: 1.00E-06
EVENT DESCRIPTION: FREQUENCY PER HOUR OF THE FAILURE OF THE HEAT TRACING FOR A PIPE
DATA VALUE SOURCE: IEEE STD 500 RELIABILITY DATA

EVENT: "HIGH SOLIDS IN 'HW' BLOCKS PIPE PROB"
DATA VALUE USED: 1.00E-03
EVENT DESCRIPTION: PROBABILITY THAT A HIGH SOLIDS CONTENT IN 'HW' CAUSES A PIPE BLOCKAGE DURING A TRANSFER
DATA VALUE SOURCE: SELECTION OF TYPICAL WASTE (INPUT TO HAZARD ANALYSIS) DOCUMENT # DR-03-00-02. MONENCO REPORT DATED 23 FEB 88

EVENT: "HIGH SOLIDS IN 'SW' BLOCKS PIPE PROB"
DATA VALUE USED: 1.00E-03
EVENT DESCRIPTION: PROBABILITY THAT A HIGH SOLIDS CONTENT IN 'SW' CAUSES A PIPE BLOCKAGE DURING A TRANSFER
DATA VALUE SOURCE: SELECTION OF TYPICAL WASTE (INPUT TO HAZARD ANALYSIS) DOCUMENT # DR-03-00-02. MONENCO REPORT DATED 23 FEB 88

EVENT: "HOLDING AREA FULL DUE TO HIGHER-THAN-DESIGN RATE OF RECEIVING DRUM WASTE PROB"
DATA VALUE USED: 4.00E-03
EVENT DESCRIPTION: HOLDING AREA FULL DUE TO HIGHER-THAN-DESIGN RATE OF RECEIVING DRUM WASTE
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "HOSE CONNECTION LEFT OPEN - LEAKS - H.E.PROB"
DATA VALUE USED: 4.00E-03
EVENT DESCRIPTION: OPERATOR FAILS TO CLOSE HOSE CONNECTION FOLLOWING USE
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "HOSE FROM TRUCK FAILS - LEAKS - PROB"
DATA VALUE USED: 3.50E-03
EVENT DESCRIPTION: UNLOAD HOSE FROM TRUCK LEAKS
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "IMPACT RUPTURE OF 'HW' CONTAINMENT IGNITES PROB"
DATA VALUE USED: 1.00E-01
EVENT DESCRIPTION: GIVEN A RUPTURE OF CONTAINMENT (DRUM, PIPE, TANK) DUE TO AN IMPACT ON THE CONTAINMENT (OR GIVEN A SOURCE OF IGNITION), THE PROBABILITY THAT 'HW' WASTE WILL IGNITE
DATA VALUE SOURCE: SELECTION OF TYPICAL WASTE (INPUT TO HAZARD ANALYSIS) DOCUMENT # DR-03-00-02. MONENCO REPORT DATED 23 FEB 88

EVENT: "IMPELLER FAILURE CAUSES TANK FAILURE PROB"
DATA VALUE USED: 1.00E-02
EVENT DESCRIPTION: PROBABILITY THAT AN IMPELLER FALLING OFF ITS SHAFT RUPTURES THE STORAGE TANK
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "IMPROPER FITTING ON HOSE CONNECTION - LEAKS - PROB"
DATA VALUE USED: 1.00E-03
EVENT DESCRIPTION: LEAK DUE TO TRUCK UNLOAD HOSE CONNECTOR NOT BEING PROPERLY FITTED TO TRUCK
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "INORGANICS UNLOADED TO RECEIVING TANK PROB"
DATA VALUE USED: 1.00E-01
EVENT DESCRIPTION: PROBABILITY THAT AN INORGANIC TRUCK IS UNLOADED TO THE RECEIVING TANK RATHER THAN TO A STORAGE TANK
DATA VALUE SOURCE: ASSUMPTION: 1 IN 10 TRUCKS UNLOADED TO RECEIVING TANK

EVENT: "LEAKING DRUM NOT PACKED IN 320 L DRUM - H.E.PROB"
DATA VALUE USED: 1.00E-03
EVENT DESCRIPTION: LEAKING DRUM NOT PLACED IN 320 L OVERPACK DRUM
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "LEAKING DRUM RECEIVED PROB"
DATA VALUE USED: 1.00E-04
EVENT DESCRIPTION: PROBABILITY THAT A GIVEN DRUM IS LEAKING WHEN RECEIVED
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "LINE MAINTENANCED FREQ"
DATA VALUE USED: 1.00E+00
EVENT DESCRIPTION: FREQUENCY THAT ANY GIVEN LINE IS PLACED IN MAINTENANCE
DATA VALUE SOURCE: ASSUMPTION: MAINTENANCE FREQUENCY FOR ANY LINE IS ONCE PER YEAR

EVENT: "LINE NOT BLANKED PRIOR TO MAINT H.E.PROB"
DATA VALUE USED: 4.00E-03
EVENT DESCRIPTION: PROBABILITY THAT A LINE IS NOT BLANKED PRIOR TO MAINTENANCE
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "LINE NOT FLUSHED PRIOR TO MAINT H.E.PROB"
DATA VALUE USED: 4.00E-03
EVENT DESCRIPTION: PROBABILITY THAT A LINE IS NOT FLUSHED PRIOR TO MAINTENANCE
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "MANUAL VALVE FAILS CLOSED PROB"
DATA VALUE USED: 1.00E-04
EVENT DESCRIPTION: PROBABILITY THAT A MANUAL VALVE FAILS CLOSED
DATA VALUE SOURCE: RASMUSSEN ET AL., "REACTOR SAFETY STUDY", APPENDIX III - FAILURE DATA, USAEC; WASH-1400 (1975)

EVENT: "MANUAL VALVE FAILS OPEN PROB"
DATA VALUE USED: 1.00E-04
EVENT DESCRIPTION: PROBABILITY THAT A MANUAL VALVE FAILS OPEN
DATA VALUE SOURCE: RASMUSSEN ET AL., "REACTOR SAFETY STUDY", APPENDIX III - FAILURE DATA, USAEC; WASH-1400 (1975)

EVENT: "MOTOR OPERATED VALVE FAILS CLOSED PROB"
DATA VALUE USED: 1.00E-04
EVENT DESCRIPTION: PROBABILITY THAT A MOTOR OPERATED VALVE FAILS CLOSED
DATA VALUE SOURCE: RASMUSSEN ET AL., "REACTOR SAFETY STUDY", APPENDIX III - FAILURE DATA, USAEC; WASH-1400 (1975)

EVENT: "MOTOR OPERATED VALVE FAILS OPEN PROB"
DATA VALUE USED: 1.00E-04
EVENT DESCRIPTION: PROBABILITY THAT A MOTOR OPERATED VALVE FAILS OPEN
DATA VALUE SOURCE: RASMUSSEN ET AL., "REACTOR SAFETY STUDY", APPENDIX III - FAILURE DATA, USAEC; WASH-1400 (1975)

EVENT: "NON-IMPACT RUPTURE OF 'HW' CONTAINMENT IGNITES PROB"
DATA VALUE USED: 1.00E-02
EVENT DESCRIPTION: GIVEN A RUPTURE OF CONTAINMENT (DRUM, PIPE, TANK) WITHOUT AN IMPACT ON THE CONTAINMENT (NO SOURCE OF IGNITION), THE PROBABILITY THAT 'HW' WASTE WILL IGNITE
DATA VALUE SOURCE: SELECTION OF TYPICAL WASTE (INPUT TO HAZARD ANALYSIS) DOCUMENT # DR-03-00-02. MONENCO REPORT DATED 23 FEB 88

EVENT: "NON-IMPACT RUPTURE OF 'IN' CONTAINMENT IGNITES PROB"
DATA VALUE USED: 1.00E-04
EVENT DESCRIPTION: GIVEN A RUPTURE OF CONTAINMENT (DRUM, PIPE, TANK) WITHOUT AN IMPACT ON THE CONTAINMENT (NO SOURCE OF IGNITION), THE PROBABILITY THAT 'IN' WASTE WILL IGNITE
DATA VALUE SOURCE: SELECTION OF TYPICAL WASTE (INPUT TO HAZARD ANALYSIS) DOCUMENT # DR-03-00-02. MONENCO REPORT DATED 23 FEB 88

EVENT: "NON-IMPACT RUPTURE OF 'NA' CONTAINMENT IGNITES PROB"
DATA VALUE USED: 1.00E-02
EVENT DESCRIPTION: GIVEN A RUPTURE OF CONTAINMENT (DRUM, PIPE, TANK) WITHOUT AN IMPACT ON THE CONTAINMENT (NO SOURCE OF IGNITION), THE PROBABILITY THAT 'NA' WASTE WILL IGNITE
DATA VALUE SOURCE: SELECTION OF TYPICAL WASTE (INPUT TO HAZARD ANALYSIS) DOCUMENT # DR-03-00-02. MONENCO REPORT DATED 23 FEB 88

EVENT: "NON-IMPACT RUPTURE OF 'ON' CONTAINMENT IGNITES PROB"
DATA VALUE USED: 1.00E-02
EVENT DESCRIPTION: GIVEN A RUPTURE OF CONTAINMENT (DRUM, PIPE, TANK) WITHOUT AN IMPACT ON THE CONTAINMENT (NO SOURCE OF IGNITION), THE PROBABILITY THAT 'ON' WASTE WILL IGNITE
DATA VALUE SOURCE: SELECTION OF TYPICAL WASTE (INPUT TO HAZARD ANALYSIS) DOCUMENT # DR-03-00-02. MONENCO REPORT DATED 23 FEB 88

EVENT: "NON-IMPACT RUPTURE OF 'SW' CONTAINMENT IGNITES PROB"
DATA VALUE USED: 1.00E-04
EVENT DESCRIPTION: GIVEN A RUPTURE OF CONTAINMENT (DRUM, PIPE, TANK) WITHOUT AN IMPACT ON THE CONTAINMENT (NO SOURCE OF IGNITION), THE PROBABILITY THAT 'SW' WASTE WILL IGNITE
DATA VALUE SOURCE: SELECTION OF TYPICAL WASTE (INPUT TO HAZARD ANALYSIS) DOCUMENT # DR-03-00-02. MONENCO REPORT DATED 23 FEB 88

EVENT: "NON-IMPACT RUPTURE OF 'WS' CONTAINMENT IGNITES PROB"
DATA VALUE USED: 1.00E-02
EVENT DESCRIPTION: GIVEN A RUPTURE OF CONTAINMENT (DRUM, PIPE, TANK) WITHOUT AN IMPACT ON THE CONTAINMENT (NO SOURCE OF IGNITION), THE PROBABILITY THAT 'WS' WASTE WILL IGNITE
DATA VALUE SOURCE: SELECTION OF TYPICAL WASTE (INPUT TO HAZARD ANALYSIS) DOCUMENT # DR-03-00-02. MONENCO REPORT DATED 23 FEB 88

EVENT: "NOT APPLICABLE"
DATA VALUE USED: 0.00E+00
EVENT DESCRIPTION: EVENT IS NOT APPLICABLE TO THE SCENARIO CODE BEING EVALUATED

EVENT: "OPERATOR DOES NOT RELEASE VACUUM TANK VACUUM H.E.PROB"
DATA VALUE USED: 4.00E-03
EVENT DESCRIPTION: OPERATOR DOES NOT RELEASE THE VACUUM IN THE VACUUM TANK BEFORE STARTING TRANSFER FROM THE VACUUM TANK
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "OPERATOR DOES NOT TURN VACUUM TANK VACUUM OFF H.E.PROB"
DATA VALUE USED: 4.00E-03
EVENT DESCRIPTION: OPERATOR DOES NOT TURN OFF VACUUM PUMP FOR THE VACUUM TANK BEFORE STARTING TRANSFER FROM THE VACUUM TANK
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "OPERATOR FAILS TO GROUND TRUCK PROB"
DATA VALUE USED: 3.00E-03
EVENT DESCRIPTION: OPERATOR FAILS TO GROUND TRUCK BEFORE UNLOADING
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "ORGANIC DRUM UNLOADED AT INORGANIC DRUM HANDLING PROB"
DATA VALUE USED: 1.00E-01
EVENT DESCRIPTION: ORGANIC DRUM UNLOADED AT INORGANIC DRUM HANDLING
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "PALLETS PER DRUM"
DATA VALUE USED: 2.50E-01
EVENT DESCRIPTION: THE INVERSE OF THE NUMBER OF DRUMS ON A PALLET (USED TO CALCULATE THE NUMBER OF PALLETS OF WASTE HANDLED)

EVENT: "PARTIALLY FULL DRUM NOT DETECTED AT DRUM OPENING STATION - H.E.PROB"
DATA VALUE USED: 4.00E-03
EVENT DESCRIPTION: THE PROBABILITY THAT IT IS NOT DETECTED AT THE DRUM OPENING STATION THAT A DRUM WAS NOT FULLY PUMPED OUT AT THE PUMPOUT STATION
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "PIPE LENGTH BETWEEN 'OR' BULK AND 'OS'"
DATA VALUE USED: 1.80E+02
EVENT DESCRIPTION: LENGTH OF PIPE BETWEEN ORGANIC BULK RECEIVING AND ORGANIC STORAGE IN METERS
DATA VALUE SOURCE: ESTIMATED FROM OWMC PLANT DRAWING

EVENT: "PIPE LENGTH BETWEEN 'OR' DRUM AND 'OS'"
DATA VALUE USED: 1.80E+02
EVENT DESCRIPTION: LENGTH OF PIPE BETWEEN ORGANIC DRUM RECEIVING AND ORGANIC STORAGE IN METERS
DATA VALUE SOURCE: ESTIMATED FROM OWMC PLANT DRAWING

EVENT: "PIPE LENGTH BETWEEN 'SW' BULK AND 'OS'"
DATA VALUE USED: 7.00E+01
EVENT DESCRIPTION: LENGTH OF PIPE BETWEEN SEGRAGATED BULK RECEIVING AND ORGANIC STORAGE IN METERS
DATA VALUE SOURCE: ESTIMATED FROM OWMC PLANT DRAWING

EVENT: "PIPE NOT DRAINED - H.E.PROB"
DATA VALUE USED: 4.00E-03
EVENT DESCRIPTION: PROBABILITY THAT A LINE IS NOT DRAINED FOLLOWING A TRANSFER
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "POLYMERIZATION IN 'HW' BLOCKS PIPE PROB"
DATA VALUE USED: 1.00E-06
EVENT DESCRIPTION: POLYMERIZATION OF 'HW' DURING A TRANSFER BLOCKS THE PIPE
DATA VALUE SOURCE: SELECTION OF TYPICAL WASTE (INPUT TO HAZARD ANALYSIS) DOCUMENT # DR-03-00-02. MONENCO REPORT DATED 23 FEB 88

EVENT: "POLYMERIZATION IN 'SW' BLOCKS PIPE PROB"
DATA VALUE USED: 1.00E-06
EVENT DESCRIPTION: POLYMERIZATION OF 'SW' DURING A TRANSFER BLOCKS THE PIPE
DATA VALUE SOURCE: SELECTION OF TYPICAL WASTE (INPUT TO HAZARD ANALYSIS) DOCUMENT # DR-03-00-02. MONENCO REPORT DATED 23 FEB 88

EVENT: "PUMP SEAL LEAK DUE TO RUNNING DRY PROB"
DATA VALUE USED: 5.00E-02
EVENT DESCRIPTION: PUMP SEAL LEAK DUE TO RUNNING PUMP DRY
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "PUMP SUCTION VALVE NOT CLOSED - ELECT/CONTROL FAILS PROB"
DATA VALUE USED: 1.00E-04
EVENT DESCRIPTION: PUMP SUCTION VALVE FAILS TO CLOSE - ELECT/CONTROL FAILURE
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "RES/SLDG IN 'HW' DRUM PREVENT PUMPING PROB"
DATA VALUE USED: 1.00E-03
EVENT DESCRIPTION: RESIDUE OR SLUDGE IN 'HW' DRUM PREVENTS OPERATOR FROM PUMPING OUT DRUM
DATA VALUE SOURCE: SELECTION OF TYPICAL WASTE (INPUT TO HAZARD ANALYSIS) DOCUMENT # DR-03-00-02. MONENCO REPORT DATED 23 FEB 88

EVENT: "STATIC GENERATED DURING TRUCK UNLOAD IGNITES FLAMMABLE VAPORS PROB"
DATA VALUE USED: 1.00E-03
EVENT DESCRIPTION: PROBABILITY THAT THE STATIC ELECTRICITY GENERATED DURING A TRUCK UNLOAD WILL IGNITE FLAMMABLE VAPORS (TRUCK NOT GROUNDED)
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "STORAGE AREA FULL DUE TO EXTENDED INCIN SHUTDOWN PROB"
DATA VALUE USED: 4.00E-03
EVENT DESCRIPTION: DRUM STORAGE AREA FULL DUE TO EXTENDED INCINERATOR SHUTDOWN
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "STORAGE AREA FULL DUE TO HIGHER THAN DESIGN RATE OF RECEIVING DRUM WASTE PROB"
DATA VALUE USED: 4.00E-03
EVENT DESCRIPTION: DRUM STORAGE AREA FULL DUE TO HIGHER THAN DESIGN RATE OF RECEIVING DRUM WASTE
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "STORAGE TANK VENT BLOCKED FREQ"
DATA VALUE USED: 3.30E-02
EVENT DESCRIPTION: FREQUENCY THAT THE STORAGE TANK VENT IS BLOCKED (MANUAL VALVE FAILS CLOSED FREQ)
DATA VALUE SOURCE: RASMUSSEN ET AL., "REACTOR SAFETY STUDY", APPENDIX III - FAILURE DATA, USAEC; WASH-1400 (1975)

EVENT: "SURGE NOT CONTROLLED BY OPER W/ HOSE PROB"
DATA VALUE USED: 5.00E-01
EVENT DESCRIPTION: PROBABILITY THE OPERATOR DOES NOT CONTROL A SURGE OF WASTE FROM A NON-PUMPABLE WASTE TRUCK WITH THE HOSE
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "TRUCK GROUND CONNECTION FAULTY PROB"
DATA VALUE USED: 5.00E-03
EVENT DESCRIPTION: PROBABILITY THAT GOOD CONTACT IS NOT MADE WHEN GROUNDING A TRUCK
DATA VALUE SOURCE: WIRING TERMINAL FAILURE, GREEN AND BOWINE, "RELIABILITY TECHNOLOGY", WILEY (1972)

EVENT: "TRUCK TILTED TOO FAST BY DRIVER PROB"
DATA VALUE USED: 5.00E-03
EVENT DESCRIPTION: PROBABILITY THAT THE DRIVER TILTS A NON-PUMPABLE WASTE TRUCK TOO QUICKLY CAUSING A SURGE OF MATERIAL TO FLOW
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "TRUCK TILTED TOO SOON BY DRIVER PROB"
DATA VALUE USED: 5.00E-03
EVENT DESCRIPTION: PROBABILITY THAT THE DRIVER TILTS A NON-PUMPABLE WASTE TRUCK TOO SOON MISSING THE UNLOAD AREA
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "TRUCK UNLOAD PUMP SHUT OFF TOO SOON - FLOW INDICATOR FAILS PROB"
DATA VALUE USED: 1.00E-05
EVENT DESCRIPTION: TRUCK IS NOT FULLY PUMPED OUT BECAUSE PUMP WAS STOPPED TOO SOON - FLOW INDICATOR FAILURE
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "TRUCK UNLOAD PUMP SHUT OFF TOO SOON - H.E.PROB"
DATA VALUE USED: 1.00E-03
EVENT DESCRIPTION: TRUCK IS NOT FULLY PUMPED OUT BECAUSE PUMP WAS STOPPED TOO SOON - OPERATOR ERROR
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "TRUCK UNLOAD VALVE NOT CLOSED BEFORE HOSE DISCONNECT - H.E.PROB"
DATA VALUE USED: 1.00E-04
EVENT DESCRIPTION: TRUCK UNLOAD VALVE IS NOT CLOSED BEFORE DISCONNECTING UNLOAD HOSE
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "TRUCK UNLOAD VALVE OPENED BEFORE CONNECTED - H.E.PROB"
DATA VALUE USED: 1.00E-04
EVENT DESCRIPTION: TRUCK UNLOAD VALVE IS OPENED BEFORE CONNECTING UNLOAD HOSE
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "VACUUM PUMP MECHANICAL FAILURE PROB"
DATA VALUE USED: 1.00E-05
EVENT DESCRIPTION: VACUUM PUMP MECHANICAL FAILS WHILE PUMPING OUT DRUM
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "VACUUM PUMP MOTOR FAILURE PROB"
DATA VALUE USED: 7.00E-06
EVENT DESCRIPTION: VACUUM PUMP MOTOR FAILS WHILE PUMPING OUT DRUM
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT: "VACUUM PUMP NOT STARTED - H.E.PROB"
DATA VALUE USED: 4.00E-03
EVENT DESCRIPTION: OPERATOR FAILS TO START VACUUM PUMP
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "VACUUM TANK PUMPED DRY PROB"
DATA VALUE USED: 1.00E-01
EVENT DESCRIPTION: TRANSFER FROM VACUUM TANK TOO LONG - VACUUM TANK PUMPED DRY
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT: "VACUUM TANK/SLUDGE HOPPER PUMPED OUT FREQ"
DATA VALUE USED: 1.00E+03
EVENT DESCRIPTION: FREQUENCY OF PUMPING OUT THE VACUUM TANK AND SLUDGE HOPPER
DATA VALUE SOURCE: ESTIMATED FROM OWMC TREATMENT FACILITY, ANNUAL OPERATIONS SUMMARY, MONENCO LETTER DATED 10 MARCH 88, UPDATED BY MONENCO TELEX DATED 21 MARCH 88

EVENT: "VALUE- 1/25"
DATA VALUE USED: 4.00E-02
EVENT DESCRIPTION: CONSTANT USED IN FREQUENCY ANALYSIS

EVENT: "VALUE- 10"
DATA VALUE USED: 1.00E+01
EVENT DESCRIPTION: CONSTANT USED IN FREQUENCY ANALYSIS

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EVENT:              "VALUE- 2"
DATA VALUE USED:    2.00E+00
EVENT DESCRIPTION: CONSTANT USED IN FREQUENCY ANALYSIS

EVENT:              "VALUE- 24"
DATA VALUE USED:    2.40E+01
EVENT DESCRIPTION: CONSTANT USED IN FREQUENCY ANALYSIS

EVENT:              "VALUE- 3"
DATA VALUE USED:    3.00E+00
EVENT DESCRIPTION: CONSTANT USED IN FREQUENCY ANALYSIS

EVENT:              "VALUE- 4"
DATA VALUE USED:    4.00E+00
EVENT DESCRIPTION: CONSTANT USED IN FREQUENCY ANALYSIS

EVENT:              "VALVE LEAK PROB"
DATA VALUE USED:    3.30E-02
EVENT DESCRIPTION: PROBABILITY OF LEAK THROUGH ON A CLOSED VALVE
DATA VALUE SOURCE: ENGINEERING ESTIMATE

EVENT:              "VALVE LEFT OPEN H.E.PROB"
DATA VALUE USED:    1.00E-04
EVENT DESCRIPTION: OPERATOR FAILS TO CLOSE VALVE
DATA VALUE SOURCE: HANDBOOK OF HUMAN RELIABILITY ANALYSIS WITH EMPHASIS ON
                   NUCLEAR POWER PLANT OPERATIONS, NUREG/CR-1278, AUG 1983

EVENT:              "VALVE PACKING LEAK FREQ"
DATA VALUE USED:    4.40E-03
EVENT DESCRIPTION: PROBABILITY OF LEAK THROUGH THE VALVE STEM PACKING
DATA VALUE SOURCE: GREEN AND BOWINE, "RELIABILITY TECHNOLOGY", WILEY (1972)

EVENT:              "VALVE STEM LEAKAGE UNDER HIGH PRESSURE PROB"
DATA VALUE USED:    1.30E-02
EVENT DESCRIPTION: PROBABILITY OF LEAK THROUGH THE VALVE STEM PACKING GIVEN
                   HIGH LINE PRESSURE
DATA VALUE SOURCE: ENGINEERING ESTIMATE
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APPENDIX H

DESCRIPTIONS OF SIGNIFICANT ACCIDENT SCENARIOS

APPENDIX H

DESCRIPTIONS OF SIGNIFICANT ACCIDENT SCENARIOS

Included in this appendix are brief descriptions of the most important accident scenario codes with respect to offsite risk, as presented in Tables 4-2 and 4-3 of Chapter 4.

Accident Scenario Code(s): M-T-reagent-10-reagent-H-I in IR area;
M-T-AC-10-reagent-H-I in IR area;
M-T-reagent-45-AC-I-I in IS area;
M-T-reagent-50-AC-I-I in IT area

Description: Release of significant quantities of H_2S, SO_2, or Cl_2 from a building vent due to the bulk unloading of a reagent or typical acidic waste into the wrong storage tank.

HAZOPS Scenarios: IR-218; IR-219; IS-212b; IT-90

Assumptions/Discussion:

- Truck receipt frequencies of 1.4/yr for $FeCl_3$, 26/yr for H_2SO_4, 1/yr for NaHS, 63/yr for NaOCl, and 51/yr for $NaHSO_3$
- Dedicated receiving bay and storage tank for each reagent; no piping interconnections
- Transfer pump started by operator in field
- No local interlock bypasses; no handwheels on valves
- Annual functional test of all interlock components
- Bar codes assigned to incoming shipments in sequential order
- Release rate and duration as calculated by Monenco

Accident Scenario Code(s): M-T-$NaHSO_3$-10-AC-I-I;
M-T-NaOCl-15-AC-I-I

Description: Release of about 0.5 kg/s of SO_2 or Cl_2 for about 30 min from the Phys/Chem Treatment Building vent due to the addition of $NaHSO_3$ or NaOCl instead of lime during treatment of typical acidic waste.

HAZOPS Scenario: IT-444

Assumptions/Discussion:

- Maximum rate of typical acidic waste treatment (6 batches/day)
- 40-m^3 batch size used for calculations
- Cause of deviation: operator selects wrong valve or recipe specifies wrong reagent
- Protection: Data Management System (DMS) alarm based on matrix of incompatible materials
- Reagent valve failing open not yet considered
- Release rate and duration as calculated by Monenco

Accident Scenario Code(s): V-Cl2-H-0

Description: Release of 200 kg chlorine gas in 40 s from the Phys/Chem Treatment Building vent due to the addition of (a) too much H_2SO_4 or (b) too little $NaHSO_3$ during treatment of typical cyanide waste.

HAZOPS Scenario: IT-233

Assumptions/Discussion:

- Typical cyanide waste is treated 50 times/yr
- Cl_2 is released if pH drops below 3
- pH drops quickly once it is below 7
- Addition of H_2SO_4 is slow enough to require 120 s to reduce pH from 12 to 7
- H_2SO_4 pump interlocked off at pH=8
- Bad signal alarms (high/low) on output signal from flow transmitter
- pH meter reliability taken as 50%
- Most likely initiating event is flow transmitter calibration drift
- Release rate and duration as calculated by Monenco (procedure described in Appendix E-6)
- "Puff" dispersion results from ORTECH International (formerly Ontario Research Foundation (ORF))

Accident Scenario Code(s): L-HW-G-1000-3-A

Description: Toxic combustion products released from the Organic Drum Storage & Handling Building vent following ignition of wastes coming from a broken line from a drum handling vacuum tank. Various line break causes.

HAZOPS Scenario: OR-OS-3'DHHW

Assumptions/Discussion:

- No curb/dike specified or defined in drum handling building design
- Entire vacuum tank contents emptied (1/2 h) before the spill is noticed

Accident Scenario Code(s): L-HW-H-152-0-A;
L-HW-G-92-0-A

Description: Toxic combustion products released from the Organic Bulk Unloading Building following rupture of tank truck due to truck not being properly grounded.

HAZOPS Scenarios: OR-87, OR-88

Assumptions/Discussion:

- When the truck explodes, not all of the waste in the truck burns immediately.

  Rather, some fraction spills into the bay and burns.

- Either the underground sludge tank is completely empty, so that 25 m^3 of waste drains to it, or it is completely full and no waste drains off from the unloading bay.

  This assumption leads to the two different liquid release codes given above.

Accident Scenario Code(s): L-ON-H-28-1-A

Description: Toxic combustion products released from organic bulk unloading upon ignition of nonpumpable organic wastes being transferred to the underground sludge receiving tank. Caused by insufficient ventilation with ignition source present.

HAZOPS Scenario: OR-400'TB

Assumptions/Discussion:

- The underground receiving tank is treated here as an open pit, so the pool size is taken as the area inside the tank, not the area of the opening.

Accident Scenario Code(s): L-HW-C-50-2-A

Description:	Toxic combustion products released from the Organic Bulk Unloading upon ignition of halogenated wastes released from a leaking transfer pump, or from a corroded and leaking receiving tank. Caused by various pipe blocks leading to dead-head pumping, or by causes of tank corrosion.

HAZOPS Scenarios: OR-338'RTA, OR-78A'RTA, OR-78A'TA

Accident Scenario Code(s): L-HW-G-1000-2-A

Description: Toxic combustion products released from the Organic Drum Storage & Handling Building vent following ignition of halogenated wastes released from the opening for maintenance of a nonblanked line.

HAZOPS Scenario: OR-OS-43E'DHHW

Assumptions/Discussion:

- Size determined by possibility that the open valves align the transfer pipe with a transfer occurring in the Organic Storage area

Accident Scenario Code(s): L-HW-B-20-0-A

Description: Toxic combustion products released from the Organic Drum Storage & Handling Building vent following ignition of a full-drum spill of typical halogenated waste at ambient conditions. Drum spilled due to drum handling accident or other cause.

HAZOPS Scenarios: OR-4 to -6; OR-28; OR-42, -43; OR-48; OR-60 and cross-references

Assumptions/Discussion:

- Numerous possible handling accidents and operator errors analyzed by Battelle
- Total frequency of drum handling accidents (dropping; puncturing; crushing; bulging drum falling off conveyor; etc.) is about 20/yr
- Probability that drum contents are spilled and ignited varies from 0.1 to 0.001, depending on whether or not drum impact is involved or forklift trucks are in the vicinity of the spill
- Release rate and duration as calculated by Battelle (methodology in report)

Accident Scenario Code(s): 0-OR-44(HW)

Description: Toxic combustion products released from the Organic Drum Storage & Handling Building vent following ignition of halogenated wastes after a drum ruptures in the drum storage area.

HAZOPS Scenario: 0-OR-44

Assumptions/Discussion:

- 10 drums of waste assumed to be involved in the fire

Accident Scenario Code(s): 0-OR-46(HW)

Description: Toxic combustion products released from the Organic Drum Storage & Handling Building vent following ignition of halogenated wastes after a pallet or other combustible material catches fire in the drum storage area.

HAZOPS Scenario: 0-OR-46

Assumptions/Discussion:

- 100 drums of waste assumed to be involved in the fire, with time required for propagation of the fire such that a minimum of 15 min is required for the wastes to be consumed in the fire

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Accident Scenario Code(s): L-HW-H-64-0-M

Description: (a) A truck containing organic waste unloads to a Phys/Chem reagent storage tank. Electrostatic charge generation and discharge from the ungrounded truck ignites a flammable vapor/air mixture inside the truck and causes rupture of the truck cargo tank.

(b) An organic waste truck unloads to a Phys/Chem reagent storage tank and is mixed with reagent remaining in the tank. Heat/pressure generation from the incompatible mixing was postulated to potentially fail the tank and cause a liquid spill.

HAZOPS Scenarios: IR-221, IR-222

Assumptions/Discussion:

- Truck volume of 20 m^3 assumed
- The dike area in the bulk reagent unloading area is 64 m^2.

Accident Scenario Code(s): L-NA-I-165-0-A

Description: Phys/Chem storage tank fails for one of the following reasons:

(a) Agitator falls off and damages tank;

(b) High pressure in tank due to a blocked vent causes the tank to fail;

(c) Low ambient temperature in the IS area causes the tank to fail; or

(d) Vacuum in the tank is drawn by pumping out the storage tank.

HAZOPS Scenarios: IS-206, IS-210, IS-225, IS-226, IS-250

Assumptions/Discussion:

- Assume that the largest tank in the IS area fails, i.e., 40 m^3.
- Dike in the IS area is 165 m^2 surface area.

Accident Scenario Code(s): L-HW-G-92-0-A;
L-HW-H-152-0-A

Description: Toxic combustion products released from the Organic Bulk Unloading Area following rupture of tank truck containing halogenated wastes. Electrostatic charge generation and discharge from an ungrounded truck ignite the flammable vapor/air mixture inside the truck and cause rupture of the truck cargo tank.

HAZOPS Scenarios: OR-87, OR-88

Assumptions/Discussion:

- When the truck ruptures, not all of the waste in the truck burns immediately.

  Rather, some fraction spills into the bay and burns.

- Either the underground sludge tank is completely empty, so that 25 m^3 of waste drains to it, or it is completely full and no waste drains off from the unloading bay.

  This assumption leads to the two different liquid release codes given above.

Accident Scenario Code(s): L-SW-H-152-0-A

Description: Toxic combustion products released from the Organic Bulk Unloading Area following rupture of tank truck containing halogenated wastes. Electrostatic charge generation and discharge from an ungrounded truck ignite the flammable vapor/air mixture inside the truck and cause rupture of the truck cargo tank.

HAZOPS Scenarios: OR-87'SW, OR-88'SW

Assumptions/Discussion:

- When the truck ruptures, not all of the waste in the truck burns immediately.

  Rather, some fraction spills into the bay and burns.

Accident Scenario Code(s): L-HW-H-107-3-A

Description: Toxic combustion products released from the Organic Bulk Unloading Area following ignition of halogenated wastes spilled either due to a faulty hose or hose connection, or due to misvalving to or from another bulk unloading bay. The line could also break on high pressure between blockages caused by internal reactions.

HAZOPS Scenarios: OR-79 to -82, OR-92, OR-101A, and OR-110

Assumptions/Discussion:

- The operator is not required to remain in the vicinity of the truck during the transfer, allowing the full contents of the truck to spill.
- The scenario assumes the possibility for receipt of a 40-m^3 truck full of halogenated waste.
